SAN FRANCISCO CLEAN WATER PROGRAM
CITY AND COUNTY OF SAN FRANCISCO

BAYSIDE FACILITIES PLAN

CITYWIDE CONTROL SYSTEM REPORT

FEBRUARY 1981

CALDWELL-GONZALEZ-KENNEDY-TUDOR
CONSULTING ENGINEERS

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February 12, 1981

Mr. Harold C. Coffee, Jr.
Project Manager, Bayside Facilities
San Francisco Clean Water Program
150 Hayes Street, Sixth Floor
San Francisco, California 94102 500-60/7

Subject: Final Citywide Control System Report

Dear Mr. Coffee:

This report presents the results of an analysis of citywide control system alternatives and describes the apparent best alternative citywide control system for wastewater flow management within the proposed sewerage system. Interim controls are also described for operation of wastewater facilities on the bay side that will be operational prior to completion, and operation of the total Bayside Facilities.

A fully-distributed supervisory control system is recommended for the key wastewater facilities and the interconnecting transport/storage elements. The citywide control system would interface with individual local controllers at remote facilities, such as pump stations, storage facilities, and treatment plants, and manipulate their operation to optimize system performance with respect to established objectives and regulatory requirements.

Specific operating protocols and procedures for all major facilities citywide will be presented in the Operational Plan Report.

Very truly yours,

Donald L. Feuerstein

Donald L. Feuerstein
General Manager

DLF:sl
Enclosure

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CHAPTER 1

INTRODUCTION

Presently, the City and County of San Francisco is divided into three separate wastewater collection and treatment systems. Each of these systems includes a combined sewer collection system and a water pollution control plant that provides primary treatment and disinfection of the combined wastewater. During both dry and wet weather, the treated water is discharged to the nearshore waters of San Francisco Bay and to the Pacific Ocean. During wet weather, flow in excess of the present treatment capacity is discharged through combined sewer overflow outfalls at 39 locations--8 on the ocean side and 31 on the bay side of the City.

The City has embarked upon a massive program to upgrade its wastewater facilities in compliance with regulatory requirements and regional objectives. As part of this program, major transport, storage, and treatment facilities have been planned for the ocean side of the City, while the construction has been completed on some key elements on the bay side. Further, a parallel planning effort is currently under way to identify the remaining elements of the wastewater system on the bay side that will bring the City into compliance with the regulatory requirements. The configuration of the facilities is based upon Master Alternative 1B, as presented in the Southwest Facilities Plan (Reference 1). The locations of existing, under construction, and planned major pumping and treatment facilities are shown on Figure 1-1.

REGULATORY REQUIREMENTS

In order to protect the beneficial uses of receiving waters, the Regional Water Quality Control Board (RWQCB), by their Order No. 79-67 (Reference 2), specified the overflow requirements for the various "diversion structures" (outfalls) along the City shoreline. These requirements not only specify the frequency of allowable overflows for planning of physical system elements, such as storage and pumping facilities, but also delineate the operation and utilization of these elements prior to and during an overflow event. The requirements that are specifically relevant to the control system planning prohibit any overflows unless all of the following criteria are met:

1. All storage capacity within a storage facility is fully utilized.

2. Maximum installed pumping capacity or some lower rate based on limits of downstream transport or treatment capabilities is being utilized to withdraw flows from the storage facility.

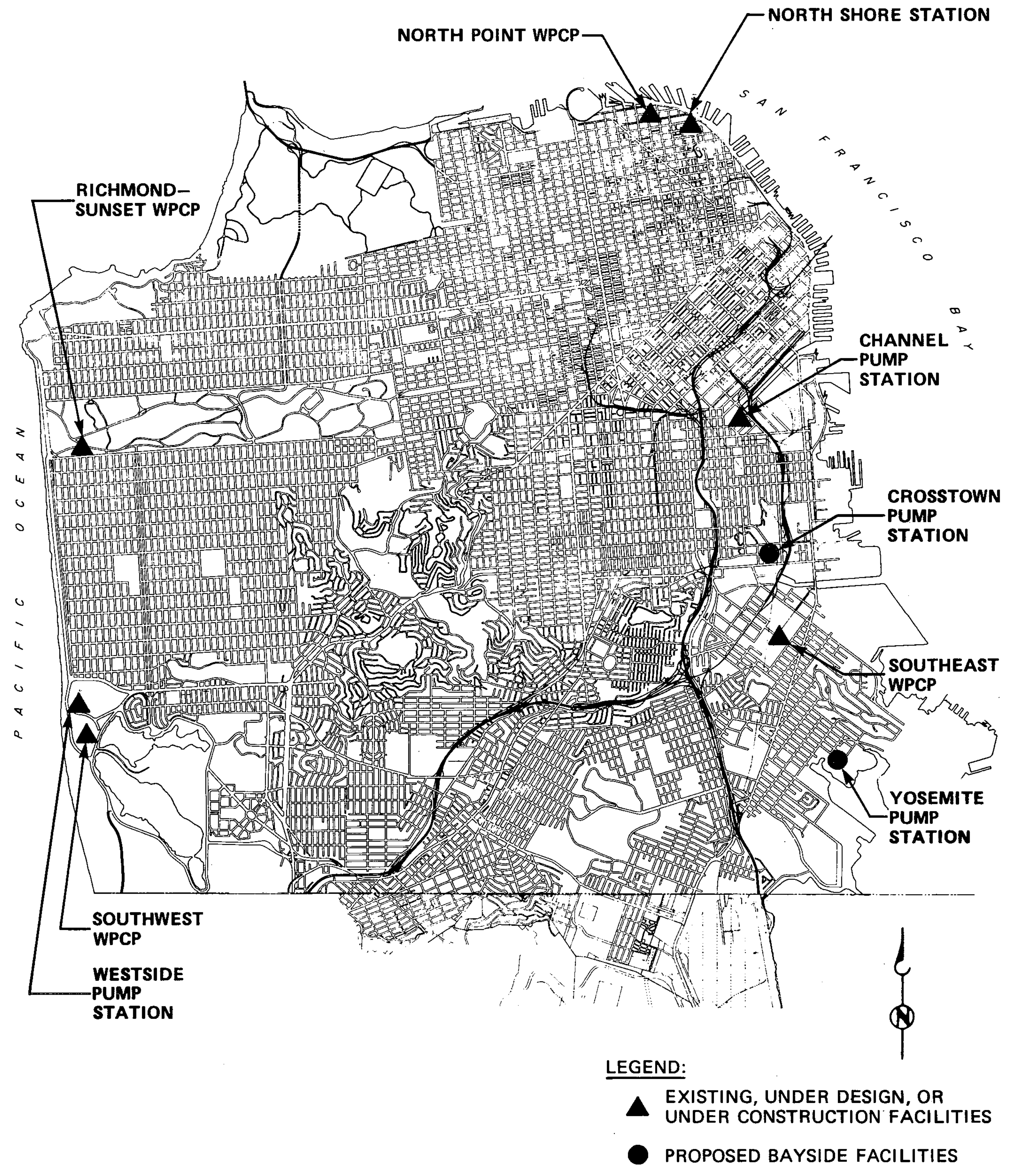


Figure 1-1 City and County of San Francisco, Major Pumping and Treatment Facilities

3. All citywide treatment facilities, excluding the Golden Gate Park reclamation facility, are being operated at capacity or at some lower rate consistent with the maximum withdrawal and treatment rates.

The above requirements, in effect, set the stage for a fairly sophisticated citywide control system that can reliably utilize all wastewater facilities in an optimized manner prior to an overflow occurrence.

OBJECTIVES AND SCOPE OF THE REPORT

The objectives of the report are to study control system options and develop a cost-effective control system for flow management within the proposed sewerage system.

The major thrust of the report is the development of a supervisory control system for the key wastewater facilities shown on Figure 1-1 and the interconnecting transport/storage elements. This control system will interface with the individual local controllers at remote locations, such as pump stations, storage facilities, and treatment plants, and manipulate their operation to optimize the system performance with respect to the established objectives and the regulatory requirements.

This report is organized into several sections. First, the planning criteria are established and the available control strategies are evaluated based on their cost-effectiveness in meeting the planning criteria. Then, as required by the recommended control strategy, data communication needs are identified for the various remote facilities and an appropriate communication network is selected. Finally, as tools for implementation of the recommended control strategy, various control configurations are identified and evaluated based upon the data communication needs and the relevant economics.

The report concludes with necessary details of hardware and software requirements for the recommended control system, and an outline of the procurement procedure to assure compatibility between the various control elements. Recommendations for interim controls are also included.

CHAPTER 2

CONTROL SYSTEM PLANNING CRITERIA

The central objective guiding the development of the citywide supervisory control system is that it must produce identifiable benefits that justify its cost. The benefits to be derived relate to the beneficial uses of the receiving waters. The regulatory requirements and conditions relating to overflows promulgated by the Regional Water Quality Control Board (RWQCB) assure that these beneficial uses are protected. With construction completed or under way on some parts of the wastewater system, and planning or design started on other elements, there are a number of control system evaluation criteria which can be identified.

COMPLIANCE WITH DISCHARGE REQUIREMENTS

The frequency of untreated combined sewer overflows must be limited as required by National Pollution Discharge Elimination System (NPDES) permits. In addition, the plan must comply with prohibition against untreated overflows unless all treatment and storage facilities are utilized to their maximum potential.

WATER QUALITY IMPROVEMENT

By optimizing the management of all wastewaters discharged to the receiving waters, the control system can reduce pollutant loads and thus improve water quality. United States Environmental Protection Agency (USEPA) Program Requirements Memorandum PRM 75-34 states that dollar costs for control of wet weather overflows "should be compared with quantified pollutant reduction and water quality improvements." The control system should integrate the controls of the Southwest Water Pollution Control Plant (WPCP), the Southeast WPCP, several pump stations, and any controlled outfall gates so that all wastewater will be processed to have minimum adverse impacts on the receiving waters. This will involve optimizing treatment of dry weather flows and treating wet weather flows by maximum utilization of available in-system storage (including the use of trunk sewers capable of storage) to minimize the total mass of pollutants emitted. With regard to combined sewer overflows, the control system must also be responsive to successive control levels and differing levels of localized control.

CITYWIDE APPLICABILITY

Because all the collection, treatment, and disposal facilities of the wastewater system must work together to meet discharge requirements and protect the beneficial uses of the receiving waters, it is important that a control system be developed that has citywide application. The available options for control systems will be judged against the criterion that the system should be capable of communicating with all existing, designed, and proposed control system elements.

To that end, the control systems to be considered will be digital systems as opposed to analog systems. While an analog control system is possible, the regulatory requirements regarding the utilization of physical facilities mandate substantial data gathering and processing capabilities. For a wastewater system of this magnitude, these capabilities can only be economically attained through a digital control system. Furthermore, a digital control system is being installed at the Southeast WPCP and the designers of the Westside Pump Station and the Southwest WPCP are also considering the use of digital controls. A digital system can be impressed upon an analog system at installations where an analog system has been employed to provide compatibility for data transmitting and receiving functions between project elements.

RELIABILITY AND FLEXIBILITY

The control system concept should be as simple as possible; an overly sophisticated control system may be less reliable because of more breakdowns in equipment and greater understanding difficulties by operators. Because the wet weather system operates only during inclement weather, it must be reliable. Further, the critical control elements should be adequately redundant to minimize performance degradation or equipment failure.

Flexibility should be built into the control system, so that an operator can transfer flow to environmentally less sensitive receiving waters, retain or store wastewater for poststorm treatment at dry weather plants, or route stormwater to the wet weather treatment plant, whichever is most appropriate. Another measure of flexibility is the capability of the control system to be compatible with both interim and ultimate control needs, and at the same time, improve the operation of the various facilities to reduce power consumption and other operating and maintenance costs. A system would certainly be favored if it is completely compatible with the interim control needs of the wastewater system. To assist with operations, the system should also provide optimum operator/process interface data logs and reports for current needs as well as for historical records.

CHAPTER 3

EXISTING CONTROL SYSTEMS

It was noted earlier that the City, in compliance with regulatory requirements, has already embarked upon the design and construction of some key wastewater treatment and pumping facilities. While the design work has been initiated on the Southwest Water Pollution Control Plant (WPCP) and Westside Pump Station, construction is substantially completed on the North Shore and Channel Pump Stations. Furthermore, the existing Southeast WPCP is currently being expanded to provide a diurnal dry weather peak secondary treatment capacity of 142 million gallons per day (mgd).

Each of these facilities has a local control system. Since any Citywide Control System must interface with all of these local controls, and conversely, the local controls must be responsive to the Citywide Control System commands, it is pertinent to briefly describe the design features and limitations of the local control systems.

SUMMARY OF EXISTING CONTROL SYSTEMS

The following paragraphs summarize the key features of existing control system designs. The information contained here is based upon a review of the contract documents, predesign reports, and memoranda pertaining to each facility.

Channel Pump Station

The construction of the Channel Pump Station is substantially completed. This facility includes a hybrid control system, consisting of Modicon Model 384A programmable logic controller (PLC) for sequential pump control and various conventional hardware for modulating control.

This equipment utilizes conventional analog instrumentation to measure pump suction channel levels and calculate the required wastewater discharge flow. An analog controller transmits pump start/stop commands to the PLC and then sends speed signals to the pump variable speed driver as necessary to maintain the required flow. Analog controllers also control the pump station inlet gates based upon the water level in the inlet channels.

The station alarms are monitored by a large annunciator system. Relay modules can easily be added to this annunciator to permit a grouping of all alarms for retransmission to the Citywide Control System.

North Shore Pump Station

Construction of the North Shore Pump Station is currently under way. The control system design for this pump station is virtually identical to that of Channel Pump Station and the contractor proposes to use exactly the same controller as that provided for Channel Pump Station.

Westside Pump Station

This pump station is presently going through a major redesign. The control system for this station, however, is expected to be based upon complete digital controls using programmable controllers to handle sequential and modulating control, and a color cathode ray tube (CRT) operator interface.

Southwest WPCP

The design work for this plant is under way. A distributed digital data acquisition and control system is being considered for this plant. This system, if implemented, will use multiple microcomputers for process control, status, and data acquisition functions. These microcomputers will be located near the processes they serve and will be coordinated by a master computer. The process instruments, actuators, and motor control centers will be hardwired to their associated microcomputers. All automatic process control loops and manually set control signals to operate these devices will be generated by the associated microcomputer.

Overall operator control will normally be from a central control console connected to the master computer. Detailed operator control of each process area may be performed at the local control console connected to its associated microcomputer. The central console will be equipped with a CRT.

Southeast WPCP

The Southeast WPCP is presently being expanded. This plant will have a central digital control system using a Modcomp Classic 7863 computer as a master controller. This computer is set up to communicate with several microprocessor-based, in-plant, remote multiplexers. These multiplexers will be located close to the various remote work stations. The remote work stations consist of local analog equipment control panels with analog to digital interfaces. The plant control system is divided into two major operation centers, namely, liquid operation center and solids operation center. A CRT is provided at each operation center as operator interface.

The multiplexers proposed for the Southeast WPCP are modular and will be suited for installation at other remote locations several miles away from the plant, if needed.

LIMITATIONS OF EXISTING CONTROL SYSTEMS

Presently, most of the above systems have no real provision for operation in a single integrated network. While each system has been provided with a port for connection to a suitable communication channel, no software (programming) has yet been provided that would define what data or control functions should be transferred over communication channels, or what protocols would be used to effect such communications. Chapter 8 of this report identifies the programming requirements for the Citywide Control System and outlines the recommendations for interface to existing controls. The establishment of a communication protocol, however, is not within the scope of this report. The protocol is generally established during the design or construction phase of the project. Therefore, it can either be provided by the control system designers, or can be specified to be established by the control system supplier.

The Modicon programmable controllers at Channel Pump Station and North Shore Pump Station do not maintain data bases in a format suitable for transmitting data on command to a central controller. The controls at these pump stations will require certain modifications, so that they can accept discharge flow signals as determined by the Citywide Control System. Appendix A describes the required modifications for these stations in detail.

The computer systems as presently planned for the Westside Pump Station, Southwest WPCP, and Southeast WPCP would be usable as remote terminal units and could be integrated into the citywide system, as described later in this report.

CHAPTER 4

ALTERNATIVE CONTROL STRATEGIES

During a storm, flow rates must be selected for major points of flow to utilize the available storage, transport, and treatment facilities in an optimized manner. For instance, at North Shore and Channel Pump Stations, some method must be used to determine what the pumping rates should be. The formal logic to make these decisions can be termed a control strategy. In this chapter, the available control strategies are discussed in terms of their effectiveness and costs. The chapter concludes with a cost-benefit analysis and a recommendation for staged implementation of the apparent best control strategy.

AVAILABLE CONTROL STRATEGIES

In general, there are two classes of strategies that may be used to control items such as pumping rates, treatment rates, and gate positions. These two classes are reactive and predictive as defined in the following paragraphs.

Reactive Control Strategies

As the name implies, reactive control strategies cause the control devices to react in response to the prevailing status of variables such as level, pressure, volume, and flow, without attempting to predict their future values. For example, the City's present wastewater pump stations operate on levels in pump suction channels to start, stop, or regulate the speed of the pumps. Likewise, the inlet gates are throttled based upon the water level in the suction channels to prevent the station from flooding.

Predictive Control Strategies

Predictive control strategies use predictions that can be made during or prior to a storm, as well as the prevailing status of physical variables. Under predictive control, the control devices would operate in a reactive mode as modified by signals based on predictions. Thus, predictive control could be described more fully as integrated reactive-predictive control. In this chapter, however, the term "predictive control" will be used for brevity.

Considering the example cited above, the pumps under predictive control would operate in a similar fashion, that is, based upon suction channel levels; however, the levels used for pump control (set points) would be adjusted when predictive control indicates improved performance.

APPLICABILITY TO CITYWIDE CONTROL SYSTEM

A previous report (Reference 3) evaluated various reactive and predictive strategies for real-time automatic control of a single storage facility with a single pump station using the North Shore Outfalls Consolidation (NSOC) system as an illustration. The conclusion of that report was that the predictive control would not be cost-effective as applied to the North Shore system. However, it became apparent during Bayside Facilities planning that predictive control deserved further investigation for the larger areas under the Citywide Control System because the eventual configuration of the wastewater facilities will permit a great degree of interaction between the various storage facilities. The different overflow requirements for adjacent drainage basins will actually encourage such interaction.

It was, therefore, decided to test predictive control against reactive control for a case of two interacting storage facilities. The reactive strategies considered are those developed for the NSOC system (Reference 3), but which are equally applicable to the Citywide Control System.

Example Application

Reactive and predictive control strategies were tested for a typical application, shown on Figure 4-1. This figure shows two storage facilities: NSOC and Channel Outfalls Consolidation. These are connected by the North Shore Pump Station and a force main serving as transport elements between the two. It should be noted that the eventual selection of the transport elements and the pumping rates may not necessarily be as shown on this figure; nevertheless, the example is realistic for testing the control strategies. It is also noted that although Figure 4-1 is based on the abandonment of the North Point Water Pollution Control Plant (WPCP), as contemplated by Master Plan 1B (Reference 1), the use of this plant during the initial stages of the recently developed implementation program (Reference 4) should not alter the basic conclusions of this report.

While, in this example, the problem is to develop a control strategy for the North Shore Pump Station, similar applications will arise elsewhere. For example, runoff from the Sunnydale and Yosemite basins must be transported toward the Islais Creek basin; these flows will be controlled by pump stations, gates, or some combination of both. Similarly, on the west side of the City, gravity flows from one section to another may be controlled by gates which will be throttled to utilize the storage in upstream sections. Furthermore, at the Channel Pump Station, control may be needed to optimize conditions downstream in the Islais Creek area. In summary, whatever the final configurations may be, there will be locations where flows from one storage facility will influence another storage facility.

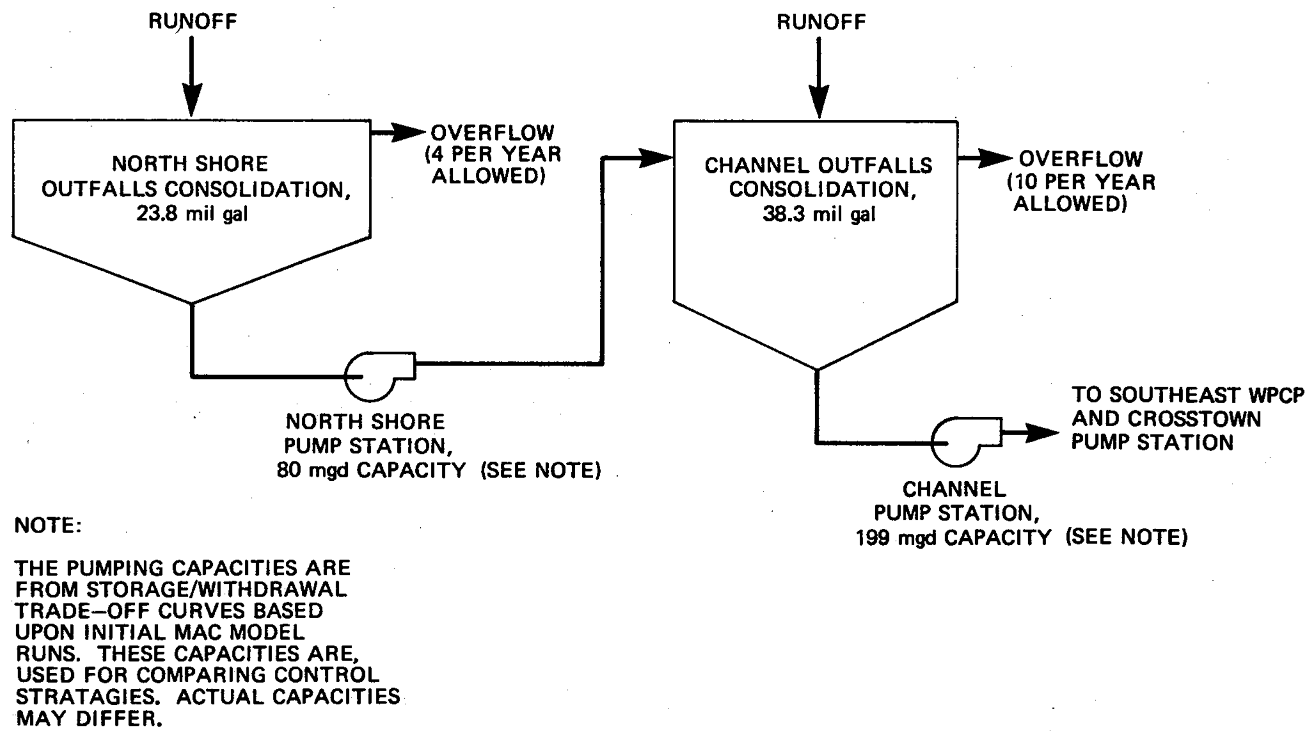


Figure 4-1 Example Application for Control Strategies

Reactive Control Strategies. Figure 4-2 is a logic diagram for the basic operating strategy, defined by the Real Time Automatic Control of Combined Sewer Systems (RTAC), Phase 1 Report (Reference 3). Figure 4-3 improves Figure 4-2 by imposing a seasonal minimum storage constraint. The latter strategy was found to be the most cost-effective for the NSOC system, based upon the objectives of the RTAC Report (Reference 3).

It is noted that the reactive strategies of Figures 4-2 and 4-3 do not use information from Channel Outfalls Consolidation in the control of North Shore Pump Station. More complex reactive strategies could be developed to use this information; however, any such strategy would require very careful testing so as not to cause excessive overflows at North Shore.

Predictive Control Strategies. Two predictive strategies are developed, namely, perfect prediction and limited prediction.

1. Perfect Prediction. Obviously, it is not possible to exactly predict rainfall. However, a hypothesis of perfect prediction was found very helpful in developing control strategies. In the example of Figure 4-1, overflow at Channel can be minimized by pumping just enough from North Shore to keep North Shore from overflowing. Thus, at the end of a storm, North Shore storage will be full. The computer would try various pumping rates for North Shore, selecting the minimum rate that does not cause overflow at North Shore by a series of mass balance calculations. For each trial pumping rate, a mass balance would be performed (i.e., predicted runoff plus dry weather flow minus pumping equals net increase in storage). The maximum storage would be compared with the storage capacity of NSOC. If overflow would occur with the trial pumping rate and a higher pumping rate is possible, the trial rate would be increased and the process would be repeated. Logic to do this is shown in simplified form on Figure 4-4.

2. Limited Prediction. The logic of Figure 4-4 requires complete information on a storm as soon as runoff begins, that is, very early in the storm. This is beyond the present capabilities of meteorology. The RTAC Report (Reference 3) recognized this problem and developed a less demanding predictive strategy. There, the logic was intended to eliminate unnecessary start-ups of large pumps. However, that strategy was designed for a single storage facility. For applications similar to the example of Figure 4-1, with two interacting storage facilities, a new strategy is required. For Figure 4-1, the central problem is to avoid excessive pumping from North Shore to Channel. Figure 4-5 shows a logic diagram for limited prediction which achieves this purpose.

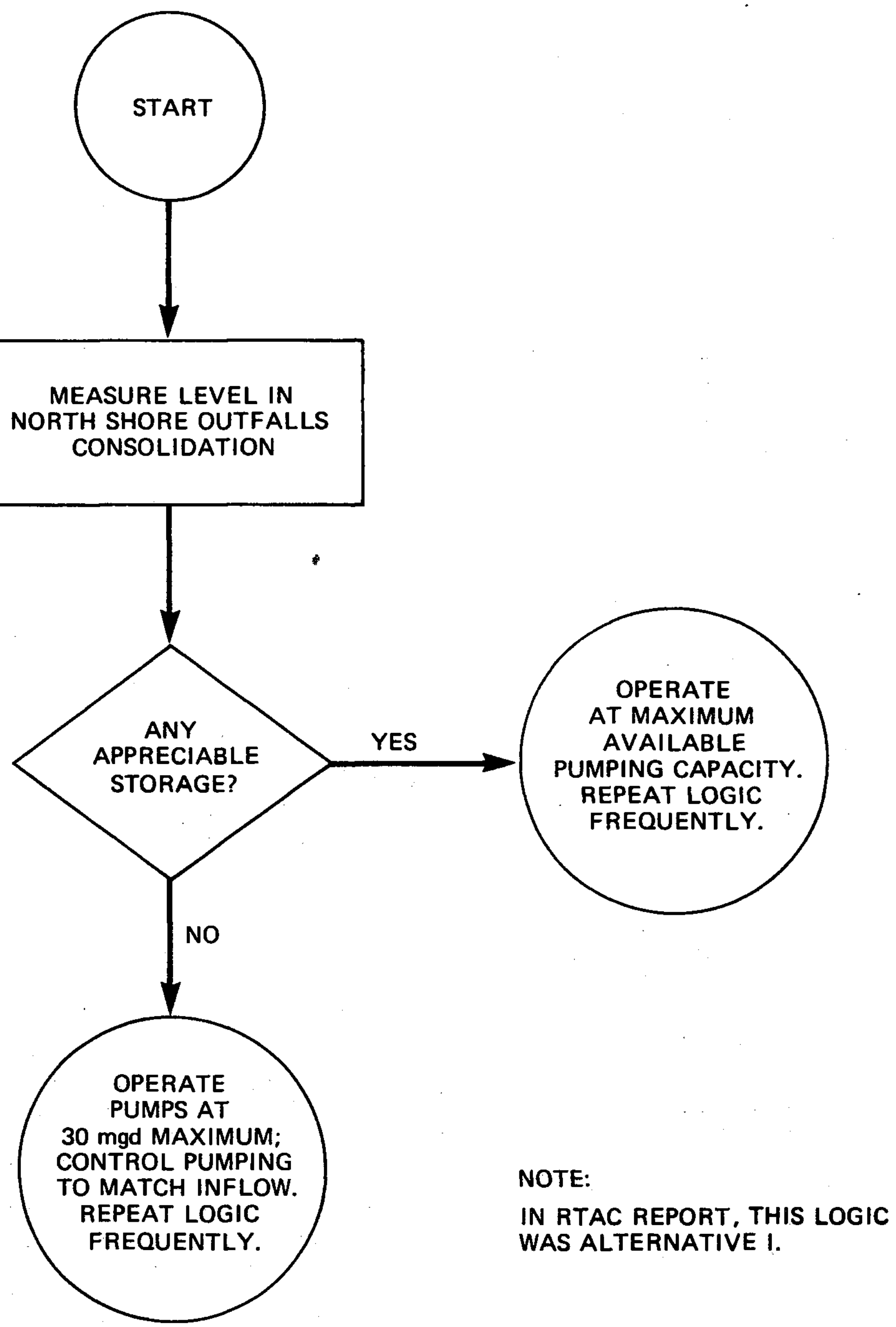
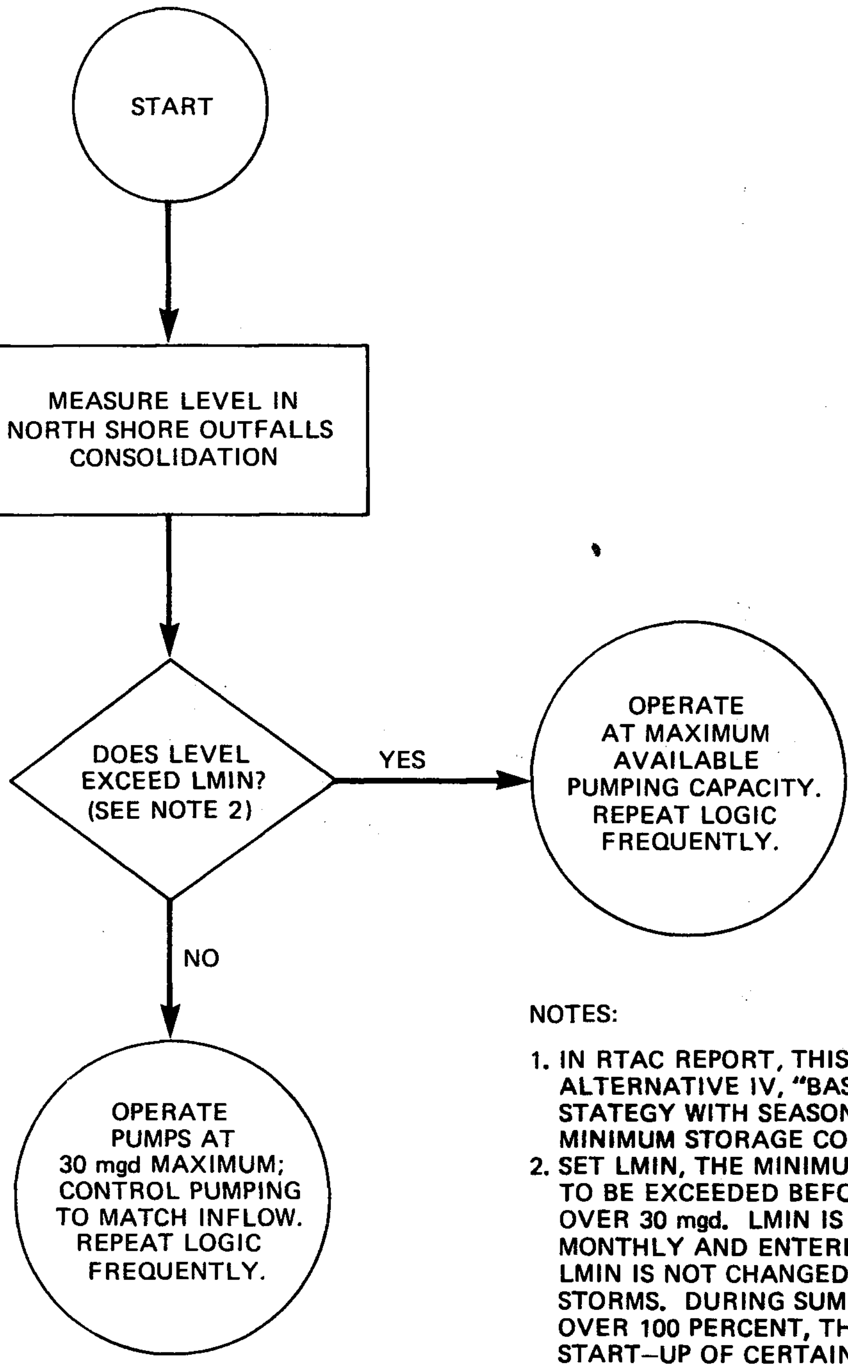


Figure 4-2 Diagram of Basic Operating Strategy for North Shore Pump Station



NOTES:

1. IN RTAC REPORT, THIS LOGIC WAS ALTERNATIVE IV, "BASIC OPERATING STATEGY WITH SEASONAL AND MINIMUM STORAGE CONSTRAINTS."
2. SET LMIN, THE MINIMUM STORAGE LEVEL TO BE EXCEEDED BEFORE PUMPING OVER 30 mgd. LMIN IS DETERMINED MONTHLY AND ENTERED BY OPERATOR; LMIN IS NOT CHANGED DURING INDIVIDUAL STORMS. DURING SUMMER, LMIN IS SET FOR OVER 100 PERCENT, THUS PREVENTING START–UP OF CERTAIN PUMPS.

Figure 4-3 Logic Diagram for North Shore Pump Station With Minimum Storage Constraint

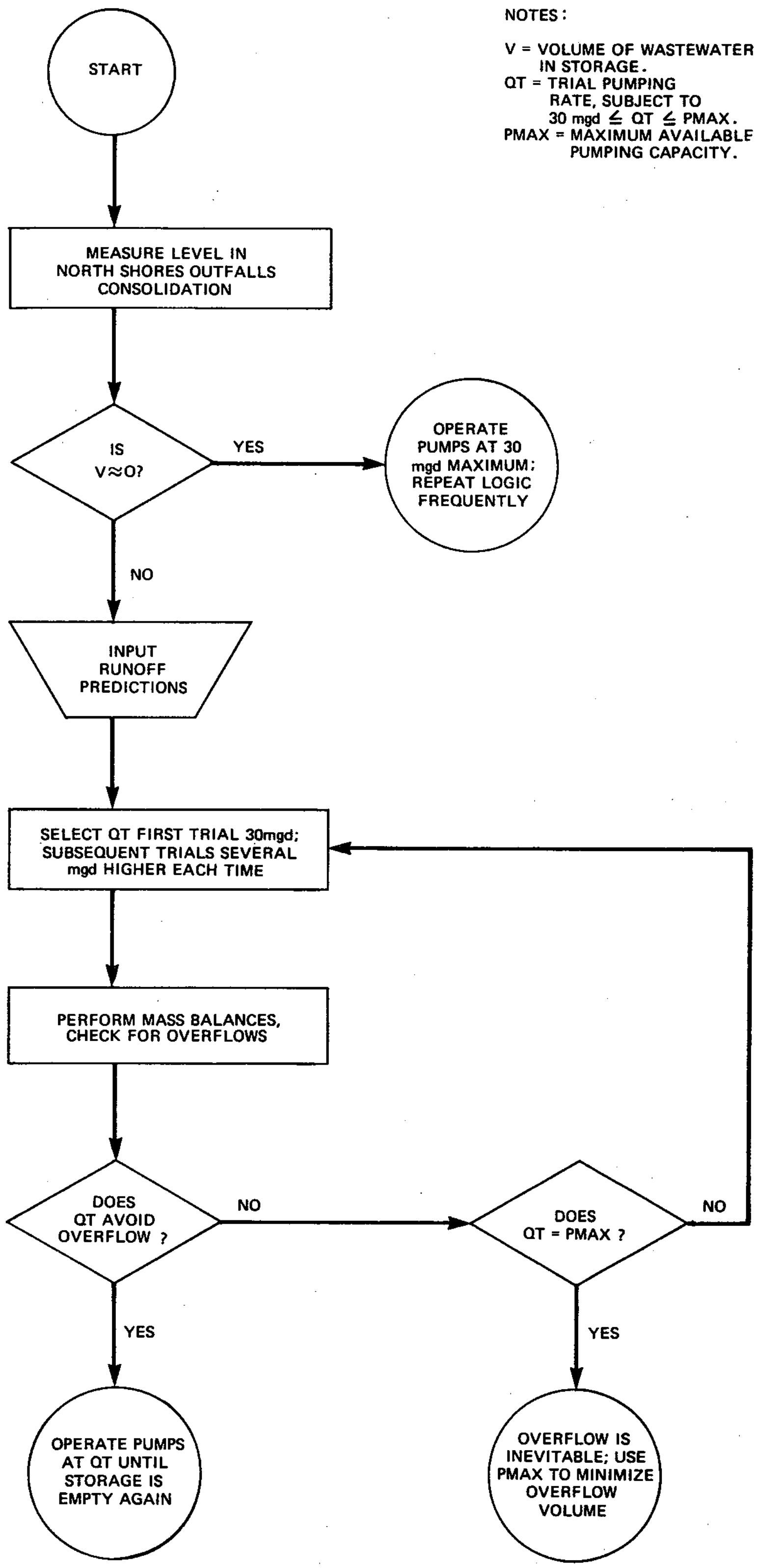


Figure 4-4 Logic Diagram for North Shore Pump Station With Perfect Prediction

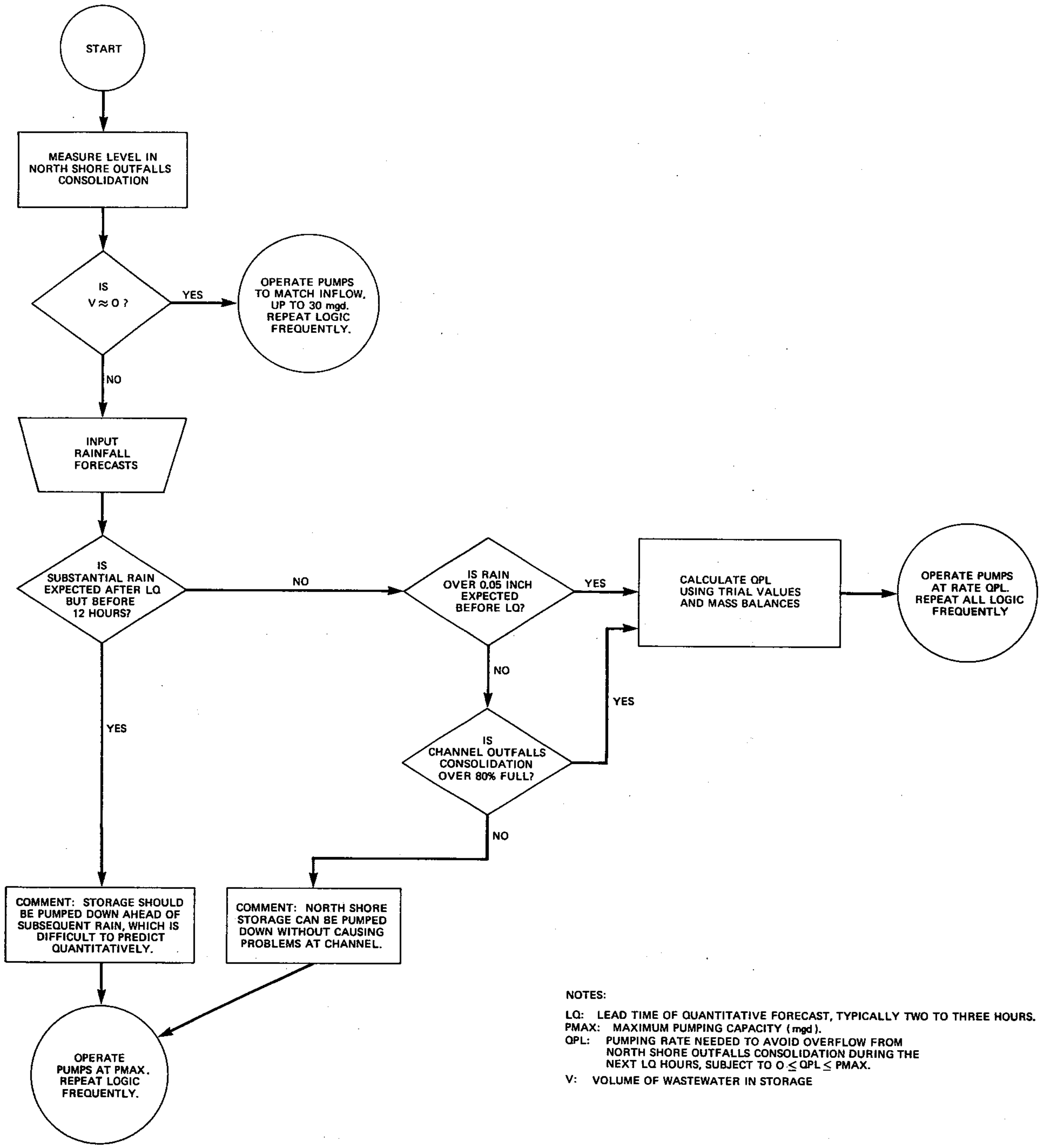


Figure 4-5 Logic Diagram for North Shore Pump Station With Limited Prediction

For each storm, more information is available as the storm progresses. Figure 4-5 uses this fact to reduce the demands on forecasting. North Shore pumps can keep up with dry weather flow plus light rain; also, stored volume can be pumped down. Therefore, the problem is to fill the storage, but avoid overflow, at the end of heavy rainfall. During the operation of wastewater facilities, one of these five conditions will apply:

1. In dry weather, North Shore should pump at a rate to match the influent flow.

2. In any substantial storm, there will be a period early in the storm when rainfall will be difficult to predict. During this period, North Shore should pump at capacity to minimize North Shore overflows, regardless of conditions at Channel. This situation derives from the National Pollutant Discharge Elimination System (NPDES) permit (Reference 2), which places stricter limits on North Shore overflows than on Channel overflows.

3. Later in the storm, rainfall becomes quantifiably predictable because the remaining rainfall can be estimated using data from the early periods in the storm and also because the lead times are short. Then, North Shore should reduce its pumping rate, pumping only enough to avoid North Shore overflow. This reduces flow into Channel and therefore reduces or avoids overflow at Channel. The North Shore pumping rate would be selected by performing a series of mass balances.

4. After a storm, Channel may be nearly full. To avoid overflow at Channel, North Shore should minimize pumping toward Channel until Channel storage has been pumped down somewhat.

5. After a storm, if Channel storage is low enough, Channel will be able to take full flow from North Shore without risking overflow. Then, North Shore pumps would transfer the stored volume to Channel for subsequent treatment.

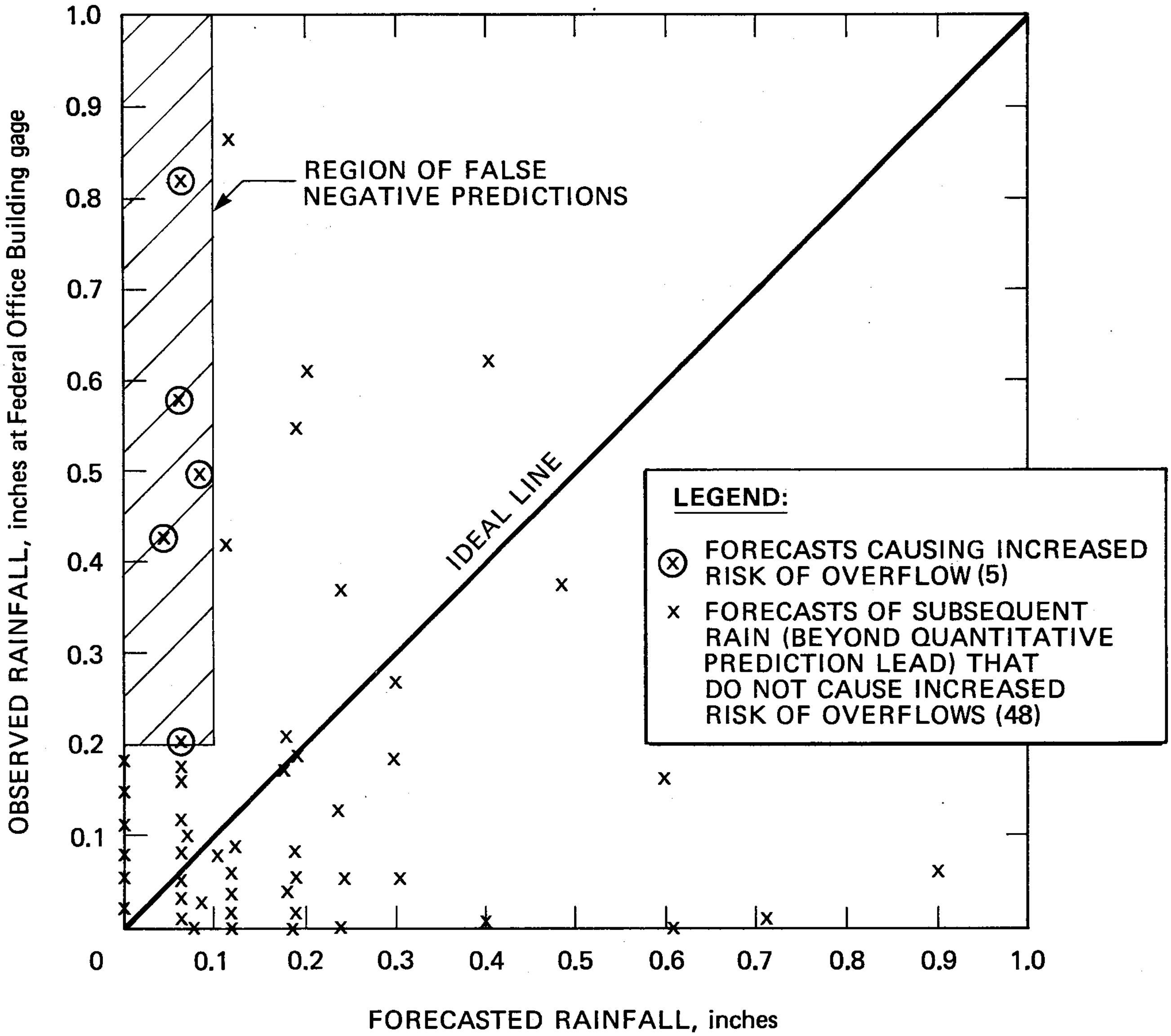
The logic on Figure 4-5 identifies which of these conditions applies and determines the appropriate pumping rate. The logic would be performed on a computer at the Citywide Control Center. For lead times over about 15 minutes, it is necessary to predict rainfall. For very short lead times, however, runoff can be computed directly from measured rainfall.

Figure 4-5 is not necessarily optimal since, during most of the runoff period, it does not use information on levels of rainfall at Channel. While these refinements can easily be implemented during the actual operation of the wastewater facilities, they cannot be tested by the present SFMAC model. Also, since this information is equally applicable to both predictive and reactive control strategies, Figure 4-5 provides a realistic comparison with RTAC-derived reactive strategies as shown on Figures 4-2 and 4-3.

Figure 4-5 requires quantitative rainfall forecasts with lead times of 1 to 3 hours. Satisfactory, quantitative 1- to 3-hour forecasts are believed to be possible, although considerable effort will be needed. An entirely automated procedure such as RAFORT (Reference 3) will be useful but, by itself, will be inadequate. This model presently uses only one or two remote raingages. Accuracy would increase if more remote gages were used by the model. However, there are inherent limits to models that use no real-time data except raingages, regardless of the number of raingages. At least one quantitative, automated procedure has been tested with networks of over 100 raingages; however, this procedure is also imperfect, largely because point rainfall data do not accurately indicate the speed and direction of storm movement (References 5, 6, and 7). No one has yet developed a usable, fully automated, quantitative rainfall forecast procedure that uses real-time data from wind instruments, satellite photographs, weather radar, or other sources in addition to raingages.

Considering the limitations of fully automated procedures, attention was given to procedures that require a human forecaster. In the Chicago area, very promising results were recently obtained with a combination method. A human operator used data from a large network of remote raingages and a weather radar; a computer was also a key element. For one complex convective storm, forecasts were issued at 2-hour leads with an average error of 0.2 inch (Reference 8). For more uniform rain, better accuracy would be obtained. Even with the best forecasts, of course, some imprecision will occur; therefore, in evaluating predictive control, some allowance must be made for this imprecision.

In addition to the quantitative short-term forecasts discussed in the preceding paragraphs, Figure 4-5 uses predictions as to the occurrence or absence of subsequent substantial rainfall. Subsequent rainfall is believed to be predictable with a satisfactory degree of accuracy. Figure 4-6 shows a comparison of regional forecasts with actual rainfall. Obviously, such forecasts are not highly quantitative. However, the logic of Figure 4-5 does not use relatively long-term forecasts (3 hours and more) in a quantitative way. All that is needed is an indication of whether or not there will be significant rain. A false, negative prediction might cause underpumping from North Shore and, therefore, an occasional increased overflow, compared to purely reactive control. A false, positive forecast is not a problem because it will merely cause the system to operate as if reactive control were in use. The record of predictions on Figure 4-6 shows very few of the troublesome false, negative predictions. The forecasts on Figure 4-6 were made for northern California; if forecasts were made specifically for San Francisco, additional improvements would be obtained.



NOTE: FORECASTS WERE TAKEN FROM NATIONAL WEATHER SERVICE RECORDS FOR CALIFORNIA AND ADJUSTED FOR SAN FRANCISCO. DATA ARE FROM A PREVIOUS REPORT. FORECAST LEAD TIMES WERE 6 HOURS. [REFERENCE 9]

Figure 4-6 Predictability of Subsequent Rain

Comparative Results for Example Application

To see how the various control strategies work, a series of storms was applied to the drainage areas of both North Shore and Channel, connected as shown on Figure 4-1. A period of January 2 to 17, 1907, was studied in some detail. Rainfall during this period is shown on Figure 4-7. This period was chosen because it included substantial rain and two storms which would have caused moderate amounts of overflows under reactive control. Three strategies were tested:

1. Reactive control, basic operating strategy, shown on Figure 4-2. (Reactive control with seasonal minimum storage constraints, shown on Figure 4-3, would produce almost identical results because the storage constraint would be zero or a low number in the month of January.)

2. The perfect predictive strategy shown on Figure 4-4.

3. The limited predictive strategy shown on Figure 4-5. Forecasts were assumed to be issued hourly, with a 2-hour quantitative lead (LQ, on Figure 4-5). That is, quantitative forecasts would be issued at 8 a.m. (covering 8 a.m. to 10 a.m.), 9 a.m. (covering 9 a.m. to 11 a.m.), and so forth. The forecasts were assumed to be correct.

The calculation procedure was a mix of a modified version of the SFMAC computer program and hand calculations.

Detailed results are shown on Figure 4-8 for the first significant storm. The following results were obtained:

1. Either perfect or limited prediction would save an overflow downstream at the Channel Outfalls Consolidation.

2. With reactive control, a downstream overflow would occur even though upstream (North Shore) storage was only about 60 percent full.

3. Perfect prediction greatly reduces the peak pumping rate at North Shore. However, this benefit is not obtained with limited prediction. Limited prediction must use the full peak pumping capacity early in a storm, when little information is available on the storm.

4. Perfect prediction required a 7-hour lead time for quantitative rainfall (6 a.m. to 1 p.m., January 4) because perfect prediction uses runoff quantities that are predicted to occur late in the storm to select pumping rates early in the storm. Very long lead times were also required for subsequent rainfall.

5. Limited prediction used a 12-hour lead time for subsequent rainfall (nonquantitative) together with the 2-hour lead quantitative forecast.

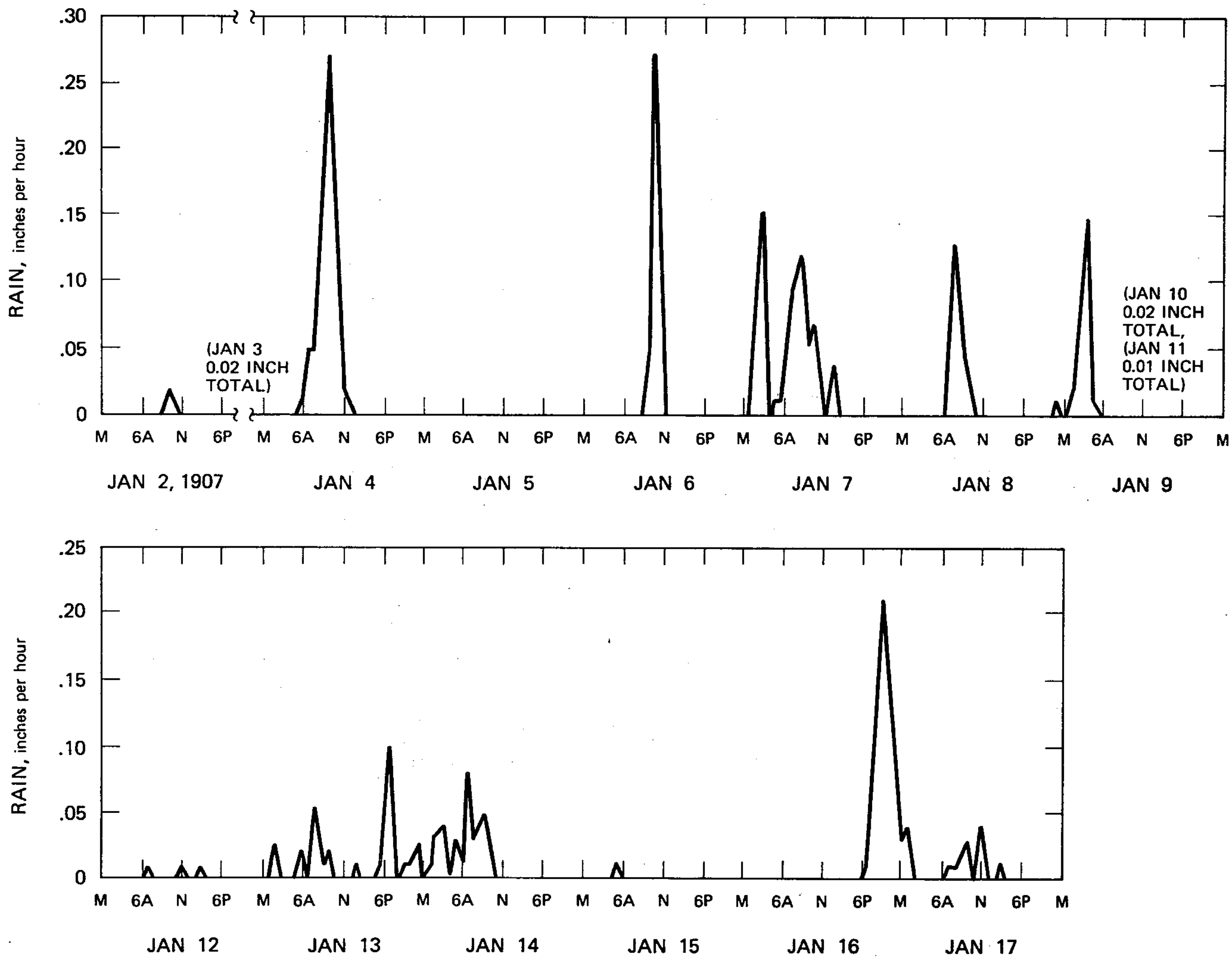


Figure 4-7 Rainfall for January 2 to January 17, 1907, Federal Office Building

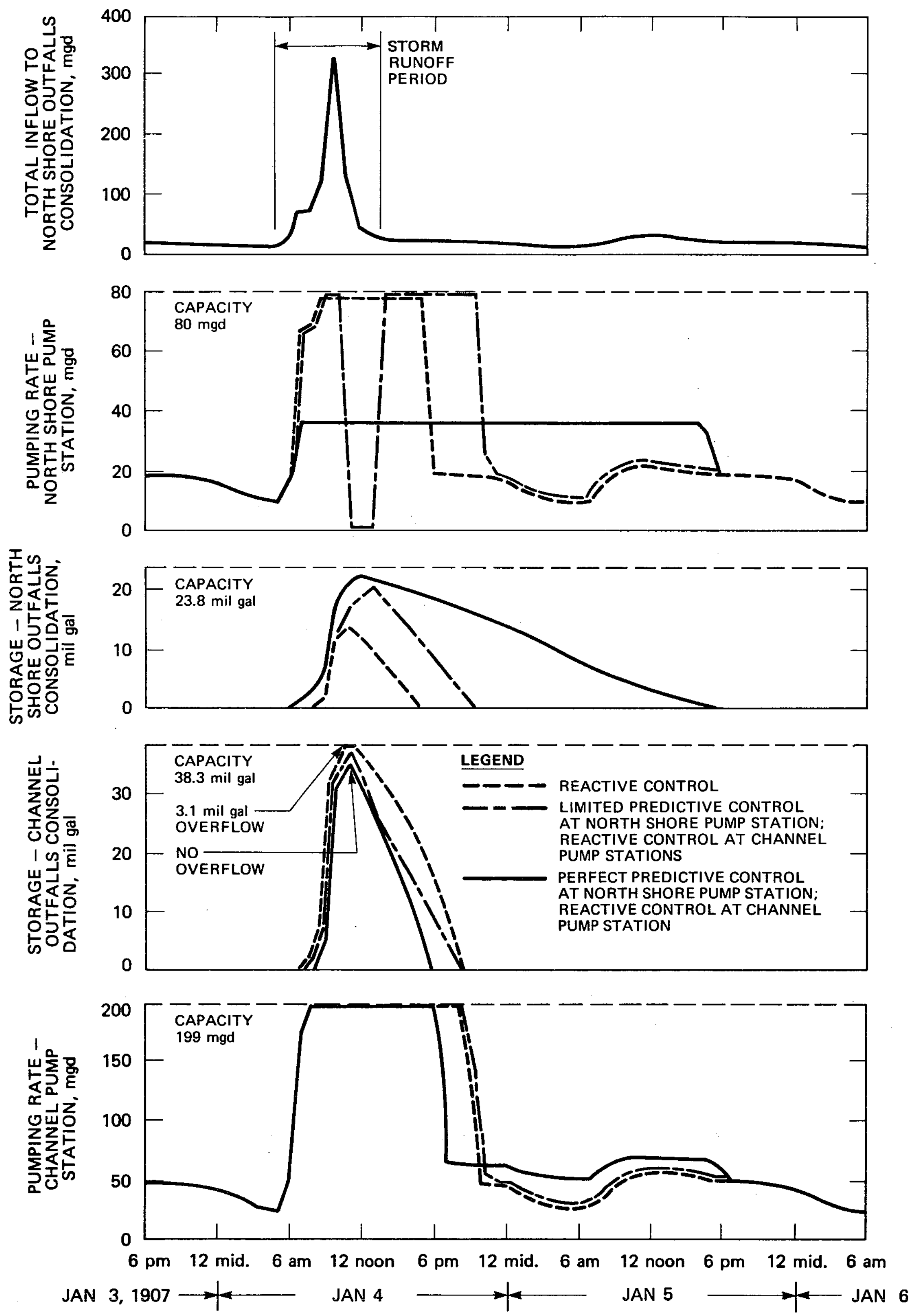


Figure 4-8 Comparative Operation With Selected Control Strategies

6. With limited prediction, the North Shore pumps shut off at the height of the storm. The pumps stay off for 3 hours. This is because of the logic used for the limited prediction strategy. Early in the storm, North Shore storage is kept as low as possible. Thus, later on, there is enough available storage to shut off the North Shore pumps, even though there is substantial rainfall; it can be forecast that this rain will not last much longer and the amount can be quantified. The North Shore shutoff is just early enough to reduce loads on Channel to prevent overflow. For the situation as it developed at 10 a.m. on January 4, with limited prediction, continuation of pumping at North Shore at that time would have caused an unnecessary overflow at Channel.

Additional results are shown on Figures 4-9 and 4-10 and in Table 4-1. The general trends are similar to those given above. During the storm of January 16 and 17, no type of control could avoid overflow, but predictive control reduces the amount and duration of overflow. Again, limited prediction works because it shuts down North Shore pumps during the latter part of the storm.

Table 4-1. Performance Improvement With Predictive Control -- Rainfall of January 2 to 17, 1970

Criterion	Reactive control	Perfect prediction at North Shore Pump Station	Limited prediction at North Shore Pump Station
Rainfall			
Total, inches	3.67	3.67	3.67
Hours with measurable rain	76	76	76
Maximum hourly amount, inches	0.27	0.27	0.27
North Shore Outfalls Consolidation and Pump Station			
Overflows	0	0	0
Peak pumping rate used, mgd	80	45	80
Peak pumping energy demand, kw	1,080	408	1,080
Maximum storage used, mil gal	15.9	22.6	20.1
Maximum duration of storage, hours from zero to zero volume	11	48	14
Hours with storage over 50 percent full	8	50	14
Number of starts of storage	10	11	10
Channel Outfalls Consolidation			
Overflow volume, mil gal	11.9	4.3	8.7
Hours with overflow	4	2	2
Overflow events[a]	2	1	1
Volume pumped to treatment, mil gal	1,257.8	1,265.4	1,261.0

[a]Intermittent overflows with a lapse time of less than 6 hours between each are counted as a single event. See NPDES Permit No. CA0038610 (Reference 2).

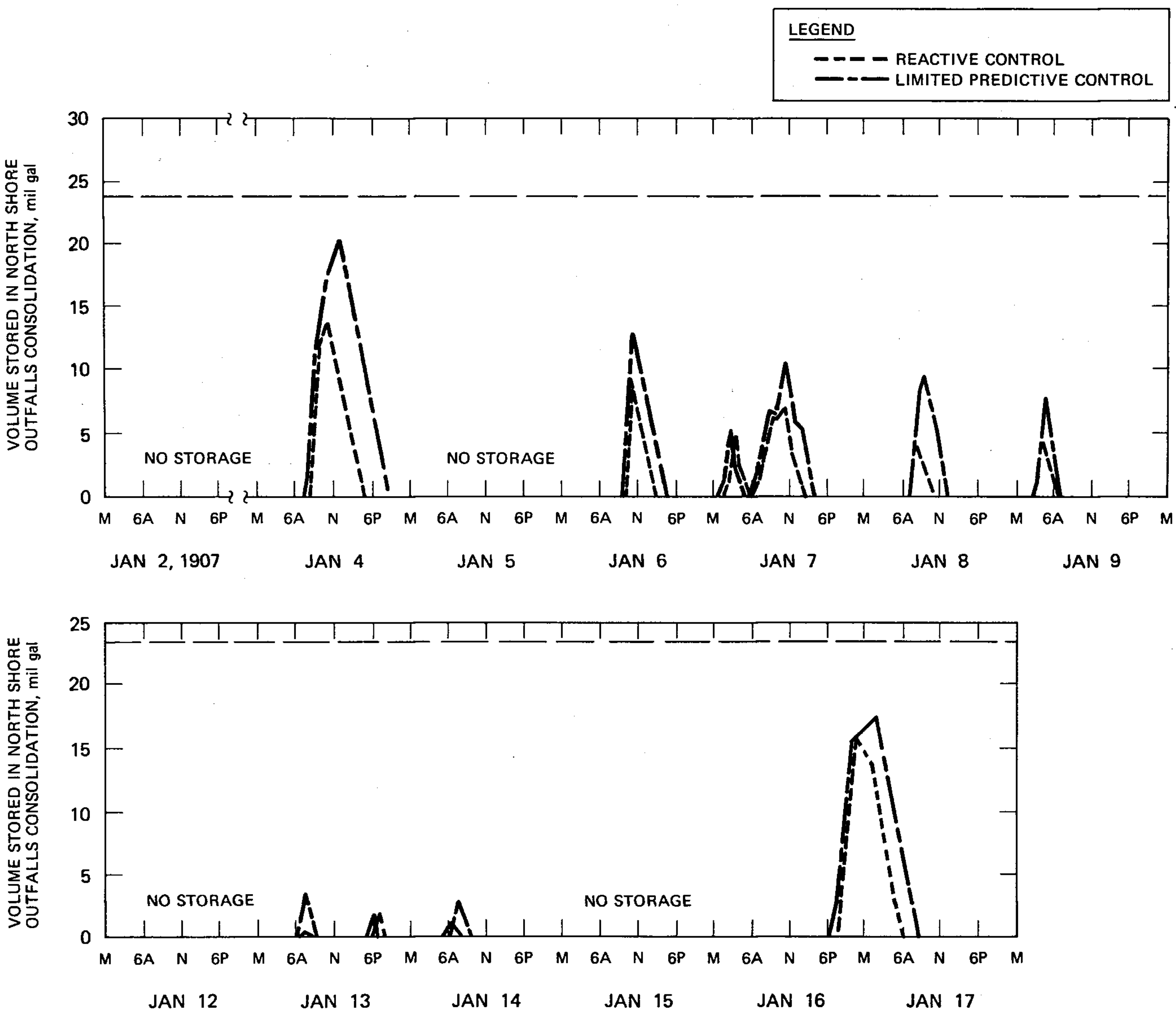


Figure 4-9 Operation of North Shore Outfalls Consolidation System With Reactive and Limited Predictive Control

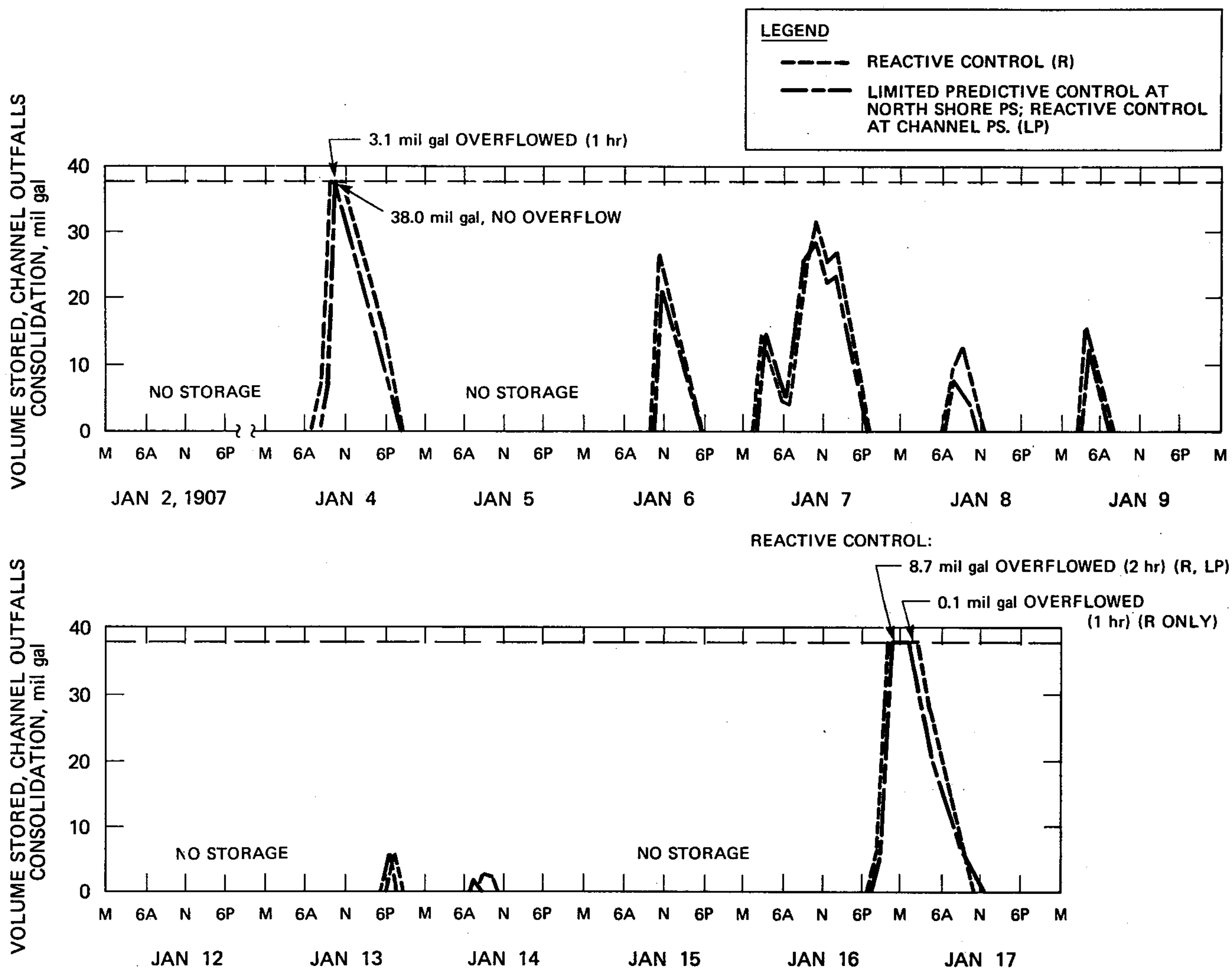


Figure 4-10 Effect on Channel Outfalls Consolidation System With Reactive and Limited Predictive Control

BENEFITS OF PREDICTIVE CONTROL

As demonstrated above, predictive control strategies, even with limited prediction, can reduce overflows in some applications. Additional benefits were considered and evaluated as discussed below; Table 4-2 summarizes these benefits. Where appropriate, dollar values for the benefits will be given subsequently.

Table 4-2. Benefit of Predictive Control for Example Application

Benefit type	Reactive control	Perfect prediction	Limited prediction
Overflows, average per year[a]	10.0	7.8	9.4[b]
Reduction in storage volume, alternative to reduced overflows, million gallons	Basis of comparison	15	4.7[b]
Storage utilization, percent[c]	60	100	80
Electrical demand reduction, kilowatts	Basis of comparison	5,000	1,000
Wet weather labor savings, work-hours per year	Basis of comparison	10,000	5,000
Wet weather treatment efficiency	Basis of comparison	Fully maximized	Moderate improvement
Overflow prioritization	Poor	Optimum	Good
Overall rating	Basis of comparison	Not possible	Moderate improvement

[a]Overflows at Channel Outfalls Consolidation.

[b]Based upon limited prediction. The benefits were discounted by 50 percent to account for inaccuracies in rainfall prediction.

[c]Storage utilization at North Shore Outfalls Consolidation in storms that are just large enough to cause overflow from Channel Outfalls Consolidation.

Overflow Reduction

The calculations for the period January 2 to 17, 1907, were able to demonstrate that predictive control is effective. The degree of effectiveness cannot be rigorously determined because without actually trying it, the accuracy of rainfall prediction is not known. However, estimates were made as to the effective increase in use of storage with predictive control for the example application of Figure 4-1.

Review of Figures 4-8 through 4-10 indicates that with perfect prediction, NSOC could contribute as much as 10 million gallons toward the effective storage capacity at Channel. That is, in certain storms, 10 million gallons extra would be stored upstream at North Shore, thereby reducing loads on Channel, and increasing the effectiveness of the Channel storage without causing overflow at North Shore. The program SFMAC showed that this addition in effective Channel storage would reduce overflow occurrences from 10.0 per year to 7.8 per year, on the average, from Channel Outfalls Consolidation, based on 71 years of rainfall records.

Similar estimates were made assuming limited prediction and accurate 2-hour quantitative forecasts issued every 30 minutes. In this case, North Shore could effectively contribute to Channel storage by as much as 5 million gallons. This would reduce overflows from 10.0 per year to 8.9 per year. Even if this figure were discounted by 50 percent to allow for prediction inaccuracy, there would be 2.5 million gallons of effective additional storage. This would reduce overflow occurrences from 10.0 per year to 9.4 per year, on the average. Thus, overflows would be reduced even after accounting for the inaccuracies of rainfall prediction.

Economy of Construction

In the previous comparison, the actual physical size of storage and pumping facilities were considered to be fixed. In that case, predictive control reduces overflows. The benefits of prediction can also be considered in another way. For instance, if the system were designed for 10 overflows at Channel, with predictive control, less storage volume would be required, thereby reducing construction cost.

The form of the savings depends on system configuration. If additional storage is to be provided at Channel, predictive control would reduce the necessary storage volume. On the other hand, if no additional storage is necessary at Channel, any savings from predictive control would be transferred elsewhere, for instance, to the Islais Creek area. Predictive control would reduce the pumping rate from Channel toward Islais Creek, thus reducing the loads and storage requirements at Islais Creek. In either case, less storage would be needed. This storage saving would be 2.5 million gallons with limited prediction, discounted 50 percent, as described previously.

To evaluate citywide savings, allowance was made for one additional interaction. Flow from the Sunnydale and Yosemite basins affects storage requirements in the Islais Creek area. With limited predictive control of the flow rate from Sunnydale and Yosemite toward Islais Creek, and fully accurate 2-hour forecasts, the Islais Creek storage volume would drop by 4.5 million gallons. Discounting by 50 percent to allow for forecast error, this saving is 2.2 million gallons, for a total bay side saving of 4.7 million gallons. With perfect prediction, the storage saving at Islais Creek is roughly estimated to be 15 million gallons. These amounts are shown in Table 4-2. No estimate was made as to any possible savings on the west side of the City.

Utilization of Storage

With predictive control, storage would be used more efficiently. Situations with overflow in one area while storage is available elsewhere would be minimized. This improves compliance with the spirit of the City's permit under the NPDES (Reference 2).

In the example application, with reactive control, Channel may overflow even though North Shore is below 60 percent full for an entire storm. With predictive control, this condition would be improved significantly, even if the predictions are only modestly accurate.

Reduction of Electrical Demand Charges

Electrical demand charges can be reduced in many months because overflows can be avoided without using peak pumping or treatment capacity. To some extent, this benefit can be obtained with reactive control by using seasonally adjusted minimum storage levels (see Figure 4-3). However, predictive control yields better results. Approximate benefits of predictive control are included in Table 4-2; these values are based on rough extrapolations from the North Shore-Channel test application to the whole City.

Reduction in Wet Weather Treatment Labor

The City's treatment plants can be operated most economically if adequate lead time is allowed to bring the wet weather treatment units on line. Under reactive controls, the wet weather pumps automatically start once the storage level reaches a preselected set point (LMIN on Figure 4-3). Therefore, in this type of control, it is implicit that wet weather treatment is available to receive and treat the pumped flow as soon as the pumps start. This approach essentially dictates a round-the-clock availability of the wet weather treatment processes during the rainy season, thus requiring substantial manpower commitment. With predictive controls, however, an advance knowledge of the incoming storm reduces the state of readiness that would be required during the wet weather months. Also, unlike a purely reactive control system, which causes the wet weather pumps to start at a predetermined set point regardless of the amount of subsequent rain, a predictive control system provides a flexibility to adjust the set point based upon forecasted rainfall. This will permit a smoother pumping operation and reduce short-term cycling of the wet weather pumps.

The value of prediction under this category is difficult to compute. At the very least, the City should anticipate two additional operators on duty throughout the wet season (7 months, 24 hours a day) for fast plant start-ups under reactive control. This would be about 10,000 work hours per year. Half of this amount might be appropriate for limited prediction, which will not completely avoid the need for fast start-ups. These amounts are shown in Table 4-2.

Treatment Efficiency

Treatment efficiency at some treatment units depends on flow. With perfect prediction, flow rates need only be as high as necessary to avoid overflow, which would increase pollutant removals. With limited prediction, however, such rate limiting is not feasible during the early and middle parts of a storm. Nevertheless, it is possible to predict the arrival of subsequent substantial rain. These forecasts could be used during the draw-down period after a storm; they would indicate the possibilities of reducing flow without increasing risk of overflow in the subsequent storm. Benefits of predictive control, then, are moderate--none during the period of high runoff, but substantial afterward, during drawdown. This benefit is, to some extent, an alternative to savings in labor cost, since the reduced flow would tend to stretch out the drawdown process.

Overflow Prioritization

When overflow is necessary, it is very desirable to be able to set priorities for overflow locations based on their environmental sensitivity. This principle has been developed in the NPDES Permit Prohibitions Analysis Report (Reference 10).

Setting priorities during overflow will be much more accurate if a careful rainfall forecasting program is used. There will be less overflow to the more sensitive locations, since the flows can be directed to the desired overflow points in a timely manner if there is an advance estimate of the total runoff from an incoming storm. Figure 4-11 shows an example of a strategy to carry out the prioritization. The basis of this figure is that the dead-end slough waters at Channel are most sensitive to overflows; the waters at Islais Creek are less sensitive; and the bay shoreline near the Bay Bridge (which is a possible overflow location for Channel Outfalls Consolidation) is the least sensitive. This basis is believed reasonable, since slough waters are more sensitive than open waters, and since the slough at Channel is used by houseboats, whereas Islais Creek has very little recreational potential (References 2 and 10). The overflow criterion is the same (10 per year) for the entire area (Reference 2), so Figure 4-11 also balances stored volumes to minimize total overflow frequency. If different overflow priorities are established, Figure 4-11 would require revision. In general, however, logic similar to Figure 4-11 can be developed wherever overflow priorities differ and there is some action (e.g., pump speeds) that can be taken.

DATA REQUIREMENTS AND COSTS FOR PREDICTIVE CONTROL

As shown above, if rainfall can be predicted with a reasonable degree of accuracy, predictive control offers appreciable benefits over reactive control. However, predictive control requires

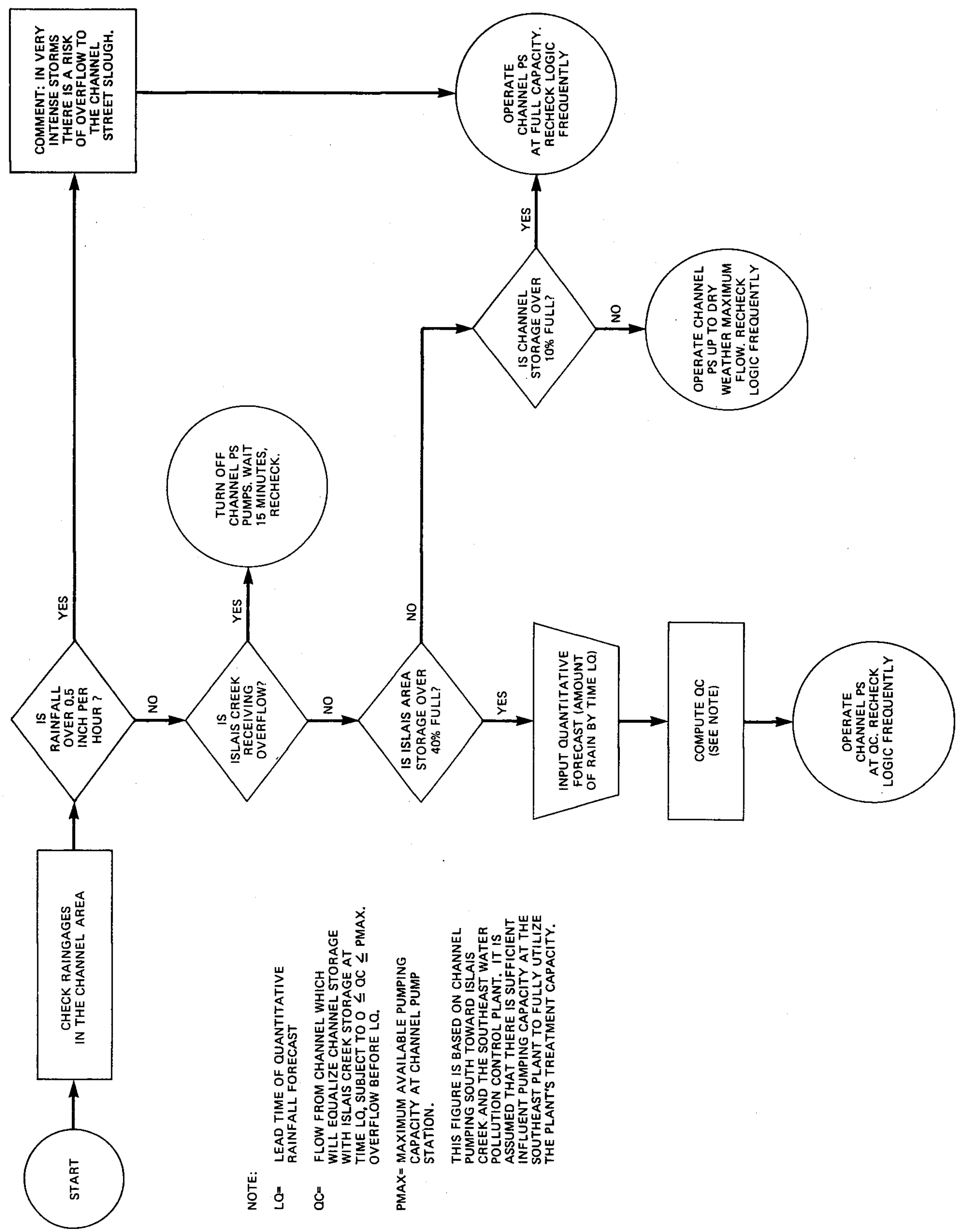


Figure 4-11 Logic Diagram for Predictive Control of Channel Pump Station

considerable meterological data. The following paragraphs describe the data requirements, associated equipment, and costs for implementing a full-scale predictive controls program. It should be noted that the type and extent of data acquisition discussed here is for achieving the maximum possible accuracy in rainfall forecasting. If the City elects to implement a predictive control program, the expenditure towards rainfall forecasting can be staged, as discussed in Appendix B.

Required Forecasts

The principal forecasts required for predictive control are described below.

Quantitative Rainfall Predictions. These would give anticipated rainfall amounts. Initial lead time of these forecasts would be 1 hour; it is hoped that reasonable accuracy may be developed for 3 hours or more. Lead times could be adjusted during storms if the forecaster chooses. These forecasts would be issued frequently, perhaps every 15 to 30 minutes during key parts of storms.

Subsequent Rain Forecasts. These would give the probability of significant rainfall in the period beyond the lead time for the quantitative prediction. These forecasts might be for 6-hour, 12-hour, and 24-hour periods, all for periods beyond the lead time of the quantitative prediction. The forecasts would be issued during wet weather. Towards the end of storms, hourly updates may be needed; otherwise, the forecasts might be issued every 4 hours or less often. These forecasts would be specifically for San Francisco, unlike the present weather service forecasts which apply to much larger areas.

Data Sources

There are two basic data sources: the National Weather Service and the City. Large amounts of data are collected by the weather service and these would be used where appropriate. It is believed that the City would require meteorologists to observe patterns and issue special forecasts. (Refer to Appendix B for a staged program which will attempt predictive control without meteorologists.) In the future, computers may be able to make such forecasts, but this technology has not yet been satisfactorily developed.

Data From the National Weather Service. The City's meteorologists would receive large amounts of data from the weather service, particularly of a regional nature. These data would be used to notify operators and meteorologists of general conditions over the next 6 to 48 hours, to generate the subsequent rain forecasts, to improve interpretation of City-generated data, and to assist in storm tracking. The weather service transmits this information virtually free of charge. The City's costs for obtaining the data would be almost entirely telephone bills and receiving equipment costs.

Weather service data would be obtained on four different types of machines: teletype, chart facsimile, photographic facsimile, and telecopier.

1. Teletype. The National Weather Service transmits regional summaries, observations, and forecasts, updated at intervals of 1 to 6 hours. The information is transmitted over telephone lines on circuit 1GT1.

2. Chart Facsimile. A chart facsimile receiver would be used for two purposes. First, regional upper air charts describe present and predicted conditions and upper level winds; these charts are of great value for storm tracking. The charts are generated by computers at the National Meterological Center in Suitland, Maryland, and distributed over telephone lines (facsimile circuit GD60144). Second, the Sacramento weather radar provides regional storm patterns and precipitation estimates. The radar operator makes notations on a chart; charts are updated hourly during storms. These charts are distributed via facsimile circuit 3GD4050.

3. Photographic Facsimile. The Geostationary Operational Environmental Satellite takes frequent visible and infrared photographs of clouds. The photographs show weather fronts and cloud systems; cloud heights may be estimated from the infrared photographs. The photographs are distributed over telephone lines from the Satellite Field Service office in Redwood City. Each subscriber has a separate facsimile circuit and a special facsimile receiver to produce photographic output.

4. Telecopier. Some weather service information is not available on the teletype and facsimile circuits noted above. Of special value in this regard are balloon (rawinsonde) data from Oakland Airport, showing local upper air conditions twice daily, and regional quantitative precipitation forecasts, issued twice daily (with occasional additional forecasts) during wet weather months. This information could be used if transmitted and received by a telecopier.

City-Generated Data. In addition to the weather service data, the City would operate a network of weather instruments.

1. In-City Raingages. A network of telemetered raingages within the City would telemeter rainfall to the Citywide Control Center. These gages would be used for short-term runoff forecasts (less than 1 hour), correlation with

remote gages, feedback to operators to improve the accuracy of quantitative rainfall forecasts, special studies, and evaluation of control. At the Citywide Control Center, the computer would make short-term runoff forecasts and comparisons with longer-term rain forecasts. Gages would be of the tipping bucket type. The San Francisco Hydraulic and Hydrologic Data Acquisition and Recording (SFHHDAR) system presently has 27 gages within the City's area of 49 square miles, or a density of 1.8 square miles per gage. The City's consulting hydrologist has proposed moving four of these gages and adding six gages in areas of special interest, for a proposed total of 33 gages. Such a network is quite dense but high density is important, especially if other equipment is deferred. Possibly, weather radar may permit a future reduction in gage density; such a reduction is not assumed in cost computations, however.

2. Remote Raingages. These gages would be mechanically similar to the in-City gages but would have a somewhat different function. The remote gages would be used to detect and measure incoming storms, to calibrate weather radar, and to supply data for computer-based rainfall forecast procedures such as RAFORT. Directions of storm approach are shown on Figure 4-12. Where practical, at least two gages should be located in each major direction of storm approach.

   Recommended locations are shown on Figure 4-13. Two of these locations are included in the City's existing SFHHDAR network. The proposed gage on Southeast Farallon Island would be more expensive than other gages to install; also, maintenance cost would be higher. However, this location is critically important for prediction because storms come frequently from the west. Southeast Farallon was selected over the other Farallon Islands because Southeast Farallon already has a lighthouse, fog horn, and radio beacon. For cost estimating purposes, it was assumed that electrical power would not be available from the Coast Guard and therefore that storage batteries, recharged by solar cells, would be used. The necessary power (only a few watts) can be obtained even in extended periods of bad weather if the solar cells are large enough. If electricity can be obtained from the Coast Guard, costs would be reduced. A second gage in the Farallones was also considered; however, access to the other islands would be very difficult.

   Data communication with these gages would be either by telephone or radio. Radio is preferred, where feasible, but telephone may be needed at some gage locations. The present SFHHDAR system does not use telephone lines with high efficiency, so the telephone costs are high. With the new system, any remote gage telephone links would be arranged on an automated dial-up basis to reduce costs. Data communication is discussed in Chapter 5.

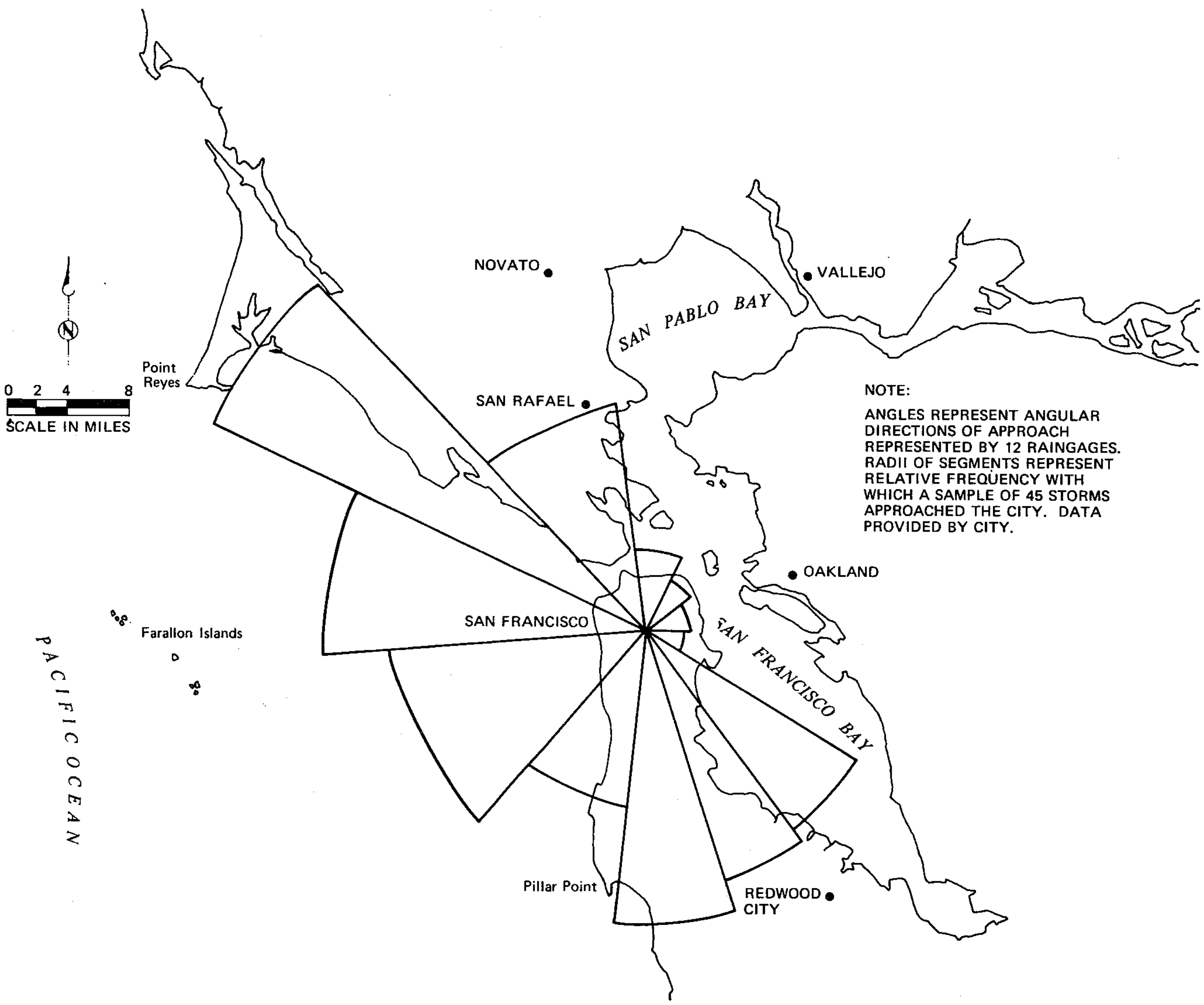


Figure 4-12 Directions of Storm Approach

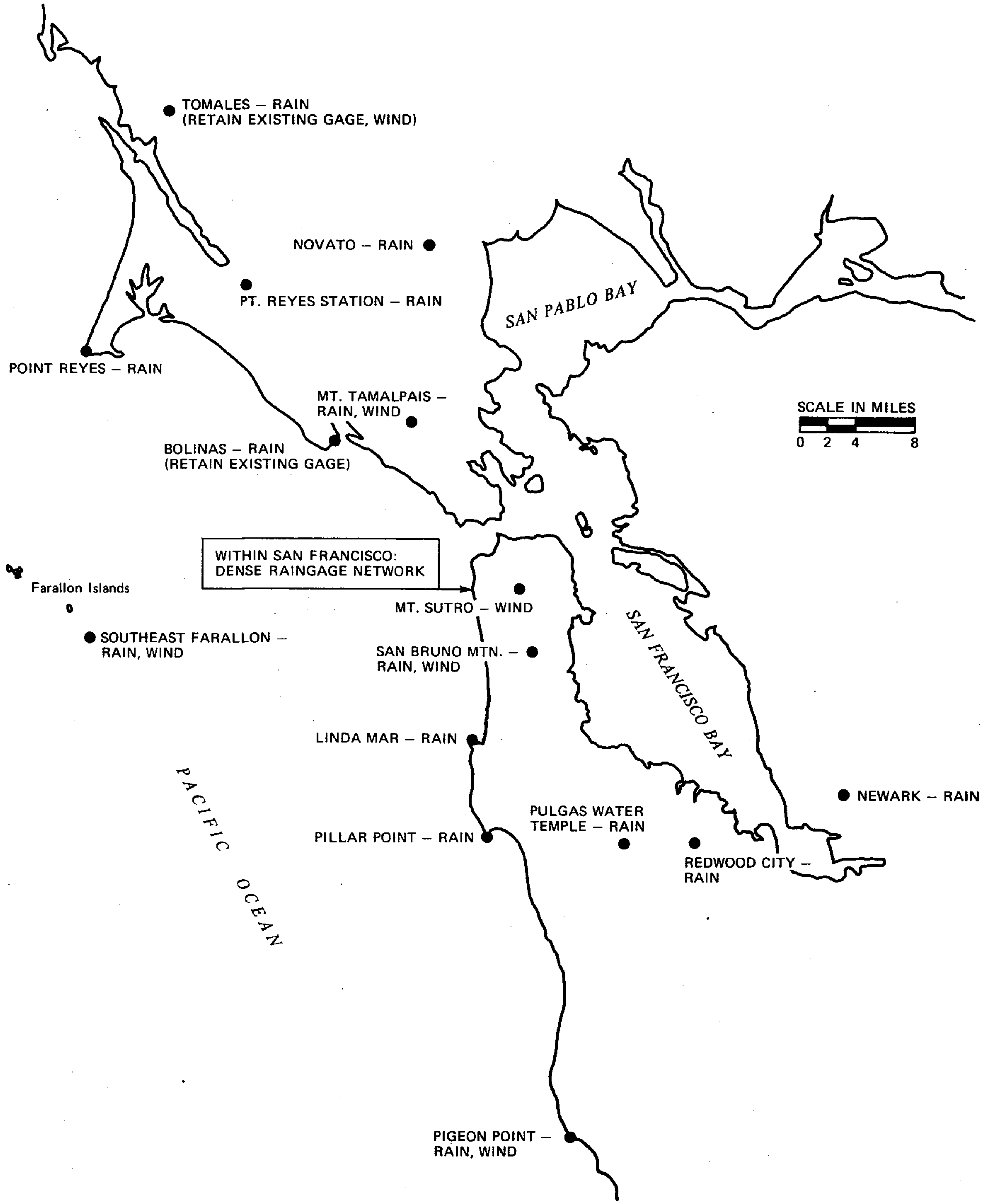


Figure 4-13 Locations of Wind Instruments and Remote Raingages for Rainfall Prediction

3. Wind Instruments. At six locations, wind speed, wind direction, and barometric pressure would be measured and transmitted to the Citywide Control Center. It is desirable to measure winds at cloud level (say, 3,000 to 12,000 feet, typically). Obviously, it is not feasible to mount gages at those levels, but locations have been selected to be as useful as possible in this regard. It may be possible to use the wind instruments to estimate winds aloft by correlations with balloon instruments and radar. Locations for wind instruments are also shown on Figure 4-13. These locations were selected to gather wind data both ahead of a weather front and behind the front as the front approaches the City.

4. Supplemental Weather Balloons. The National Weather Service presently releases two rawinsonde weather balloons a day from Oakland. These provide temperature, humidity, pressure, and wind readings at various levels in the atmosphere. It is desirable to have updates more frequently during storm periods. The City could release and track additional rawinsonde balloons. Alternatively, radar-reflective balloons without radio transmitters could be tracked by a tracking radar. The need for supplemental balloons has not been definitely established at this time.

5. Weather Radar. Raindrops within clouds reflect radar; thus, storms may be located and tracked at a distance. Storms may miss individual raingages yet be clearly detectable by radar; also, radar shows storm shape, trends, and travel much better than a rain gage network. This greatly improves predictions of arrival time. Storms often approach San Francisco over the Pacific Ocean which greatly limits possible raingage locations. Even in inland locations, the combination of radar and remote raingages is more effective than raingages alone. The Sacramento radar of the National Weather Service would provide some information, although it serves a large area and its data are not corrected for observed rainfall. It appears that for maximum accuracy in rainfall prediction, San Francisco should consider its own radar.

   Weather radars are extremely diverse in cost and capabilities (see Appendix C). At one extreme is the wide capability weather radar--it can measure one storm behind another, it has long range, it can measure cloud heights, it has the ability to distinguish many different raindrop sizes simultaneously, and it possesses elegant signal processing. This instrument costs about $700,000. At the other extreme, marine radars for navigation can be purchased for less than $25,000 new or $4,000 used; also, airplane weather radars are available in the under-$25,000 price range. Considering the capabilities and costs of the various types of radar, it is tentatively recommended that the the City consider a hydrologic radar costing about $275,000. Additional costs are estimated at $295,000 for a site, remote control, installation, engineering, and contingencies. Radar poses a number of questions that are difficult to answer at present. These questions should not be addressed immediately; they can be postponed until a late stage of a staged implementation program. (Refer to Appendix B for staged implementation.)

Data Analysis and Forecasts

Having collected large amounts of data, the City must convert the data into usable forecasts. At the present state of the art, maximum accuracy is obtained with both a computer and meteorologists.

Computer. The Citywide Control Center will have some type of computer in any event, whether or not rainfall is predicted. Some added capacity may be needed for predictive control. The programs would include the following:

1. Runoff Model. This model will convert rainfall (both observed and predicted) into runoff flow rates, with adjustments as may be indicated by runoff measurements.

2. Quantitative Prediction Program. An upgraded version of RAFORT (Reference 3) will make predictions based on data from outlying raingages. With a number of outlying gages, the program will make several forecasts simultaneously; the consistency of these forecasts may provide a useful estimate as to the predictability of a given storm. If future developments permit, additional data (satellite, radar, and winds) will be added to this program.

3. Cloud-Level Wind Estimator. Ground-level wind speeds and directions and barometer data will be used to estimate winds at various cloud levels and in various areas. This program will use rawinsonde ballon data for calibration.

4. Forecast-Checking Program. This program will compare all predictions with actual rainfall.

5. Mass Balance Program. This program will compare flow rates with changes in storage.

6. System Simulator. During a storm, when an operator is considering overriding the normal computer operation, the operator may use this program to check as to how the system would respond to various patterns of rainfall that have occurred in previous storms for both normal and manual control. During dry weather, the system simulator would be used to test various strategies, both to refine the strategies and to train the operators.

Meteorologists. The present state of computer technology is not sufficiently advanced to utilize certain types of data. Examples of such data include satellite photographs and weather radar displays. Therefore, it is anticipated that he City will require meteorologists for maximum accuracy and lead times. The meteorologists can also perform some operational functions, thus partially reducing the need for other operators. During the summer, the meteorologists would not need to issue many forecasts; their time could be productively used in studying storm records and updating the various computer programs. Operating experience will doubtless show numerous opportunities for refining the procedures of making and using predictions.

Two meteorologists should be able to perform the necessary work. During periods of stormy weather, they would be on call for alternating 12-hour periods. However, stormy periods have frequent breaks of several hours. During these periods, and during the early parts of rainfall events, a meteorologist would not have to be on duty.

Costs

The costs of the total forecasting program are summarized in Table 4-3. As shown, the totals are about $900,000 in capital costs and $230,000 per year operation and maintenance costs (January 1980 dollars).

BENEFIT-COST ANALYSIS

Since some of the benefits of prediction have economic value, a rough benefit-cost analysis can be developed. Table 4-4 shows the results of such an analysis. The bulk of the dollar benefits are in reduced storage. No credit was taken for reduced pumping capacity which might be possible. Savings were considered only for North Shore (assisting Channel and Islais Creek) and for Sunnydale and Yosemite (assisting Islais Creek), as discussed earlier in this chapter. The cost-benefit analysis shows a net benefit of over $5 million and benefit-cost ratio of over 2.5 to 1. From this analysis, one could justify implementing the entire forecasting program.

It is not desirable, however, to depend on predictive control at the present time. As described above, estimates have been made of the storage volume which could be saved by predictive control. These estimates are not highly reliable because quantitative rainfall prediction is not a well-developed science. No one has much experience at making the quantitative, short-term forecasts that are necessary for predictive control. Thus, to be conservative, storage volumes should be provided that ensure that NPDES permit requirements are met with purely reactive control. Consequently, the largest dollar benefit of predictive control is not available, and the full predictive control program is not presently cost-effective.

Table 4-3. Incremental Costs of Predictive Control - ENR 3800

Cost item	Capital,[a] thousand dollars	Operation and maintenance, thousand dollars per year[a,b]
National Weather Service data:		
Teletype (basis: Xtel AH/P-11R)	3	1
Chart facsimile (basis: Alden 9271 DH, leased)	-	4
Photographic facsimile (basis: UPI Unifax, leased)	-	7
Telecopier (leased)	-	1
City-generated data:		
Maintain existing raingage network, including Bolinas, and Tomales gages	-[c]	-[c]
Add 11 land-based remote raingages; 4 of these sites will also have wind instruments	80	20
Add 1 wind-measuring station (Mt. Sutro)	10	1
Add rain and wind data, Farallon Island (Basis: Climatronics EWS with solar power, radio transceivers, associated equipment, and installation)	40	3
Supplemental weather balloons	-	20
Weather radar (Basis: Enterprise Electronics hydrologic radar, C band, with installation remote communication)	570	20
Meteorologists (salaries, benefits, overhead, and supervision)	-	150
Computer software and programming, incremental	200	5
Total	903	202

[a]Costs in this table are incremental costs for predictive control; cost items that are common to both reactive and predictive control are not included. These common costs are about $3.9 million in capital cost and $550,000 per year in operation and maintenance (see Chapters 5, 7, and 8). Costs are based on Engineering News-Record Construction Cost Index of 3800 (January 1980). Capital costs include construction contract costs plus 35 percent for contingencies, engineering, and other project costs.

[b]Operation and maintenance costs include telephone charges, where appropriate.

[c]Included in reactive system.

Nevertheless, predictive control offers numerous operating benefits and the potential of future construction savings. Operating benefits include better utilization of storage, labor savings, higher treatment efficiency, and better overflow prioritization. Future construction savings would arise if overflow frequencies are to be reduced more than required by the present NPDES permit (Reference 2). A dollar spent on improved control will probably reduce overflows more than a dollar spent on additional storage volume, up to the limit of a full predictive control program. Also, a staged program for predictive control is quite practical (see Appendix B). Therefore, the following items are recommended to the City:

1. The City should plan to operate with introductory predictive control (see Appendix B) when the Citywide Control System is operational. Incremental costs for predictive control at this stage are about $300,000 in capital and $30,000 per year in operation and maintenance. These are modest sums in relation to the Citywide Control System ($3.9 million in capital plus $550,000 per year in operation and maintenance for citywide controls without any predictive capability), much less to the total Clean Water Program.

2. Storage volumes should be sufficient to meet the NPDES permit with reactive control.

3. The City should defer additional expenditures on predictive control until operating experience has been gained with introductory predictive control. At that time, the City will have better information on the cost-effectiveness of the additional expenditures. The additional expenditure will probably be cost-effective if it is mandated that overflows be reduced below the levels obtained with reactive or introductory predictive control.

Table 4-4. Benefit-Cost Analysis of Predictive Control

Benefit or cost, compared to reactive control	Present worth, million dollars[a]
Dollar benefits	
Economy of construction, if applicable[b]	7.1
Electrical demand reduction	0.05
Labor saving for wet weather treatment	1.3
Operation and maintenance savings on reduced storage[b]	0.05
Total dollar benefits	8.5
Cost of prediction	3.3
Net benefit of prediction	5.2
Benefit-cost ratio	2.6

[a] Present worth basis, 20 years, 7.125 percent discount factor, zero salvage.

[b] This dollar benefit assumes the reduction of storage capacity with predictive control; therefore, overflow frequency stays about the same. Storage reduction costs are based on $1.50 per gallon reduction, which includes 35 percent for contingencies, engineering, and other project costs. This is appropriate for reservoirs with complete washdown equipment and odor control. If in-street transport/storage facilities were to be used, the savings would be larger. If storage volume cannot be reduced, then this dollar benefit would not apply; however, overflow frequency would be reduced.

CHAPTER 5

DATA COMMUNICATION ALTERNATIVES

Communication and data interconnection are the keys to the establishment of a citywide control approach. This approach dictates that all necessary information regarding the prevailing status of wastewater hydraulics (flows and water levels) and remote regulator mechanisms (sluice gates and pumping equipment) be available at a central location. With this information, a central controller can then manipulate the operation of all facilities to route, limit, divert, transfer, store, and treat combined wastewater utilizing the entire system in an optimized manner. This information is also crucial for implementation of the control strategies discussed previously.

DATA MONITORING NEEDS

Data monitoring needs can generally be divided into two categories: (1) status monitoring of various parameters such as flows, levels, rainfall rates, and availability; and (2) alarm monitoring of conditions such as equipment malfunction.

Regarding the first category, a realistic appraisal of data monitoring needs must be made to assure that all vital information is transmitted to the appropriate control locations for execution of established control functions. Under the second category, however, the information to be monitored is heavily dependent upon the structure of the City's operating and maintenance organization. If the facility is to be attended, very little information needs to be monitored by the supervisory control system; but if the facility is visited by a roving crew at relatively infrequent intervals, or only in case of malfunction, more extensive information should be provided.

In general, the following information should be monitored from major remote facilities:

1. Flow in major conduits.
2. Level in pump suction channels.
3. Level in storage facilities (including conduits capable of storage).
4. Miscellaneous parameters, such as pumping rates, gate positions, overflow rates, and overflow durations.

5. Equipment status such as "ready" and "running" for major pumping units and gate operators.

6. Alarms, grouped to some extent as dictated by the maintenance organization.

The detailed data monitoring needs are best defined once the scope and configuration of the facilities to be controlled are firmly established. However, since the planning of the physical facilities has not yet matured, a tentative process input/output schedule representing the most promising physical system elements on the bay side has been prepared and is included in this report as Appendix D. The schedule also includes the data to be monitored for those ocean side facilities that are presently being planned, except for certain transport/storage elements which are relatively undefined.

The proposed schedule represents only the data requirements for overall monitoring and control of the various remote facilities. No attempt has been made to identify specific instrumentation needs for each facility for local monitoring and control purposes. The local monitoring and control requirements are highly specific to each design and can never be fully anticipated during the planning phase. This responsibility must, therefore, properly rest with the facility designers.

It is also noted that the proposed schedule is prepared as a guide for control system designers and for estimating system hardware requirements. Any changes in the scope or configuration of the physical facilities would likely change the data requirements. The effect on the present planning considerations would be minor, however, because of the flexible nature of the control system configurations discussed later in this report.

The input/output schedule (Appendix D) contains data monitoring needs for the two categories indicated above. The real-time monitoring of combined wastewaters for various water quality parameters, including suspended solids, turbidity, chemical oxygen demand, and total organic carbon was also considered. However, the specific process instruments required for water quality monitoring have historically demanded a high degree of maintenance. From a practical standpoint, the frequent maintenance of these instruments would be cumbersome, particularly since they would be scattered throughout the City. Furthermore, the benefits of such monitoring are not apparent since the flow management and control of the various transport/storage and pumping facilities should principally be based upon the water quantity rather than quality.

COMMUNICATION NETWORK ALTERNATIVES

There are two basic approaches to obtaining a communication network for transmission of the collected data from one point to another. The first is to lease channels from a common carrier such as the telephone company. The second is to construct and maintain a privately owned network. Within these two basic approaches, several alternatives can be readily identified; these alternatives are discussed here in detail.

Common Carriers

The common carriers are regulated by governmental agencies. The services they can offer are described in tariffs published by these agencies. Pacific Telephone Company and Western Union are the only common carriers presently franchised to offer intracity service. Western Union facilities, however, cover very limited areas of the City, and therefore cannot be considered a viable option. A third common carrier, Viacom Inc., although not presently franchised to offer data communication service, is also discussed since it has the potential to offer this service in the future.

Pacific Telephone. Pacific Telephone is regulated by the State of California Public Utilities Commission and offers several different types of data communication services. The most common is designated type 3002 circuit which is similar to ordinary voiceband telephone circuits. Since the type 3002 circuit was basically designed to provide voice communication, it is generally considered unsuitable for high speed data transmission. However, this type of circuit can be "conditioned" to improve its transmission characteristics and permit higher speed communication. The conditioned circuit considered here is designated type 3002C2. The technical characteristics of this circuit are also used to describe communication channels derived from sources other than the telephone company; thus, this is a common performance standard for communication channels.

A second type of telephone company circuit frequently used for data transmission is the type 1001-1006 series. This type of circuit is presently used by the San Francisco Hydrologic and Hydraulic Data Acquisition and Recording (SFHHDAR) system. These circuits were designed to provide telegraph service and do not support high enough transmission speeds for modern data acquisition systems.

The telephone company's switched network may also be used for data communication. In this arrangement, the control system automatically dials the telephone number of a remote facility. A field terminal unit (FTU) at the remote facility automatically answers the telephone and reports any data required and responds to the commands by the control system. This system, while economical, is very slow and susceptible to failure during any kind of civil emergency. The switched network, therefore, will not be considered further.

Sample rental rates for telephone circuits are shown in Appendix E.

<u>Viacom Incorporated</u>. Viacom Incorporated is regulated by the City of San Francisco and maintains a wideband communication network which serves parts of the City. This network is designed for transmission of television signals, but is also technically capable of data transmission. Viacom officials have verbally indicated an interest in providing this type of service, but the southeast areas of San Francisco, where many of the transport/storage and pumping facilities will be located, are not covered by TV cables at this time.

<u>Private Network</u>

As indicated above, the City can erect and maintain its own communication network. This network may be based on land lines, radio communication, or a combination of the two.

<u>Land Lines</u>. The land lines require the installation of an underground raceway system interconnecting the various facilities. In many cases these raceways can follow the routing of the open-cut type transport facilities and can be installed at the time these facilities are being constructed, thus minimizing the trenching and other installation costs. Installation of raceways along tunnel routes presents a more difficult problem. Separate routing at ground level is very expensive and disruptive. An alternate is to utilize submarine type cables for installation within the tunnels. Such an installation would be quite economical, but cable maintenance would require dewatering and ventilating the tunnel.

Once the raceway system has been installed, several data transmission options exist. The first option is to install a conventional multipair telephone cable. Transmission speed over conventional wire pairs is severely limited, however, and a number of pairs would be required in order to provide sufficient capacity.

As a second option, a pair of coaxial cables can be installed in the raceway system. Coaxial cable works well with multiplexing equipment similar to the digital carrier systems used by telephone companies between offices. This equipment provides a large number of high quality circuits over a single pair of cables.

The most recent advancement in telephone circuitry is the use of fiberoptic cables. The fiberoptic cables are completely immune to electromagnetic interference. This advantage is very significant in San Francisco where electric traction lines produce large amounts of interference. Another advantage of fiberoptics is that while multipair or coaxial systems are seriously degraded by moisture, small amounts of moisture in the fiberoptic cable will not affect its signal transmission characteristics. It is for this reason that fiberoptics are most suitable for installation in the tunnels.

Radio Communication. Radio communication is regulated by the Federal Communications Commission (FCC) which acts as a licensing authority for all such communication. The availability of frequencies for poin to point (stationary) applications is very limited in the Bay Area due to the high demand by numerous entities. In general, two types of radio systems can be used an ultra-high frequency (UHF) system; and a line-of-site (LOS) microwave system.

UHF frequencies are generally available for hydrological data acquisition systems which include raingage networks. UHF frequencies for general-use supervisory control systems are mostly unavailable; but even if they were available, permissible speeds would be too slow for the citywide control needs. Therefore, UHF is not a viable option for the Citywide Control System.

Low-density (narrow band) LOS microwave frequencies are available in most areas. Low density microwave can provide a number of good quality communication channels suitable for moderate speed data and voice communication. As the term implies, a LOS microwave system requires an unobstructed path between antennas. In order to meet this requirement, substantial towers would be necessary at various facilities as well as one or more repeaters in order to relay microwave signals over or around San Francisco hills.

Performance Criteria and Comparisons

The most significant measures of communication channel performance are speed, reliability, and error rate.

The communication channel speed required by the Citywide Control System is dependent on channel configuration and on the acceptable time delays for transmitting data from remote terminals to the area control center. Generally, the most stringent requirements occur when the operator manually enters a command at a control center and then waits for a return verification that the command has been executed. Psychological studies indicate that the operator should receive verification within four seconds of sending a command to a remote station. Assuming the data base listed in Appendix D with allowance for 100 percent expansion and for system efficiency, these criteria can b met with the following transmission rates:

1. Supervisory Control Center to Area Control Center--19,200 BPS (bauds per second, i.e., the number of discrete states that can be transmitted over a channel in one second).

2. Area Control Center to Remote Terminal Unit--1200 BPS.

3. Area Control Center to Telemetry Terminal--300 BPS.

4. Raingage locations have no control and may be adequately served at 75 BPS.

Channel reliability is difficult to predict. Pacific Telephone channels will have relatively low reliability for two reasons: telephone cables are suspended from poles along roadways and are subject to damage from vehicular traffic; also, telephone circuits are assembled from numerous segments which are connected together in telephone offices. Similar segments provide service to thousands of customers and require constant rearrangement to accommodate service changes.

Microwave systems utilize fairly complex electronic equipment which is subject to periodic failure. In addition, antenna structures must be placed in locations which are exposed to the wind and weather and are frequently damaged during storms.

Underground cable systems are the most reliable. If properly constructed and maintained they are virtually immune from failure except in case of possible damage during subsequent trenching operations.

The final communication channel performance characteristic is error rate. All types of communication channels periodically introduce errors in digital transmission systems. These errors are generally caused by electrical noise. Telephone systems are subject to frequent electrical interferences because electrical noise may be coupled from other circuits in the same cable with the City's circuits. Fiberoptic cables are immune from noise interference; however, the termination equipment is still susceptible to noise and occasional transmission errors do occur.

RECOMMENDED COMMUNICATION NETWORK

As noted above, all communication network options are susceptible to occasional transmission errors and can be unreliable, particularly during storm conditions when the data communication is needed the most. Therefore, it is recommended that all major wastewater treatment and pumping facilities be linked by a dual communication network. For true redundancy, the two networks must be completely independent of each other. The facilities recommended for a dual link include: Southeast Water Pollution Control Plant (WPCP), Southwest WPCP (including Westside Pump Station), Crosstown Pump Station, North Shore Pump Station, Channel Pump Station, and Yosemite Pump Station.

All other facilities, such as smaller sewerage system pump stations, can be served adequately by a single communication link. Because of their small size, these facilities generally contribute little towards system optimization; that is, even if the supervisory control communication were lost, there would be little or no increase in overflow volume.

The primary communication links between major facilities should be completely under the control of the City in order to assure that maintenance can be performed consistent with the reliability requirements of the Citywide Control System. These links can be composed of microwave; land lines, either coaxial or fiberoptic; or some combination thereof. The monetary costs for three primary network options are presented in Tables 5-1, 5-2, and 5-3. These options are:

1. A complete land line network using fiberoptic transmission, as shown on Figure 5-1.
2. A combination microwave/fiberoptic network.
3. A combination microwave/coaxial cable network.

The two latter options are represented by Figure 5-2.

Table 5-1. Fiberoptic Transmission Costs - ENR 3800

Component	Quantity	Unit cost, dollars	Total cost,[a] dollars
Capital costs			
Fiberoptic cable within existing conduit[b]	27,000 linear feet	1.50	40,500
Fiberoptic cable within new conduits	30,000 linear feet	5	150,000
Fiberoptic cable in tunnels	32,000 linear feet	4	128,000
Voice frequency/digital multiplexer drivers	9 each	10,000	90,000
Subtotal	-	-	408,500
Contractors overhead and profit (30 percent)	-	-	122,500
Subtotal	-	-	531,000
Engineering and contingencies (35 percent)	-	-	185,000
Total capital cost	-	-	716,000
Total present worth	-	-	716,000
Equivalent annual cost ($716,000 x 0.0953)	-	-	68,000

[a]Based on Engineering News-Record Construction Cost Index of 3800 (January 1980). Equivalent annual cost calculations are based upon 20-year life of all components.

[b]Existing conduit between NSOC and Southeast WPCP.

Table 5-2. Microwave/Fiberoptic Transmission Costs - ENR 3800

Component	Quantity	Unit cost, dollars	Total cost,[a] dollars
Capital costs			
Fiberoptic cable within existing conduit[b]	27,000 linear feet	1.50	40,500
Voice frequency/digital multiplexer drivers	3 each	10,000	30,000
100-foot tower (SEWPCP)	1 each	15,000	15,000
Microwave radios	10 each	10,000	100,000
FDM multiplexer channel set	30 each	1,500	45,000
Path survey and license application	Lump sum	-	15,000
Subtotal	-	-	245,500
Contractors overhead and profit (30 percent)	-	-	74,000
Subtotal	-	-	319,500
Engineering and contingencies (35 percent)	-	-	112,000
Total capital cost	-	-	431,500
Present worth of site rental (at $6,000 per year)[c]	-	-	44,500
Total present worth	-	-	476,000
Equivalent annual cost ($476,000 x 0.0953)	-	-	45,000

[a]Based upon Engineering News-Record Construction Cost Index of 3800 (January 1980). Equivalent annual cost calculations are based upon 20-year life of all components.

[b]Existing conduit between NSOC and Southeast WPCP.

[c]Site rental is for dishes required for microwave transmission.

Tables 5-1, 5-2, and 5-3 present total capital costs, the operation and maintenance (O&M) costs that are unique to each option, and the present worth costs. Other O&M costs are assumed to be roughly equivalent for all options and are not included in the tables.

In addition to the above, two other options, namely, a complete microwave system, and a complete coaxial system, were also considered but were discarded for two reasons.

Based upon a preliminary desk-top survey, it was discovered that a complete microwave system required repeaters (antennas with microwave dishes), at several locations including two hilltops outside the City, namely Volmer Peak, Berkeley, and San Bruno Mountain. These repeaters are required to circumvent the line-of-sight problems between the major facilities. This option appeared very impractical, and therefore, was dropped from further consideration.

Table 5-3. Microwave/Coaxial Transmission Costs - ENR 3800

Component	Quantity	Unit cost, dollars	Total cost,[a] dollars
Capital costs			
Coaxial cable within existing conduit[b]	27,000 linear feet	3.50	94,500
FDM multiplexer channel sets	40 each	1,500	60,000
100-foot tower (at SEWPCP)	1 each	15,000	15,000
Microwave radios	10 each	10,000	100,000
Path survey and license application	Lump sum	-	15,000
Subtotal	-	-	284,500
Contractors overhead and profit (30 percent)	-	-	85,000
Subtotal	-	-	369,500
Engineering and contingencies (35 percent)	-	-	129,000
Total capital cost	-	-	498,500
Present worth of site rental for microwave dishes (at $6,000 per year)	-	-	44,500
Total present worth	-	-	543,000
Equivalent annual cost ($543,000 x 0.0953)	-	-	52,000

[a]Based upon Engineering News-Record Construction Cost Index of 3800 (January 1980). Equivalent annual cost calculations are based upon 20-year life of all components.

[b]Existing conduit between NSOC and Southeast WPCP.

Similarly, the complete coaxial cable system was also dropped because coaxial cable is not suitable for installation within the tunnel portion of the Crosstown Transport Facility.

Review of Tables 5-1, 5-2, and 5-3 indicates that the combination microwave/fiberoptic network is the least expensive of the three alternatives. As noted earlier, however, the alternatives that utilize microwave systems require antenna structures. These structures are not without environmental impact and are subject to damage during storms. Also, the required transmission speeds over narrow-band microwave system would necessitate the use of elaborate nonstandard equipment which will further reduce the reliability of the microwave system. An additional concern regarding the use of a microwave system is that

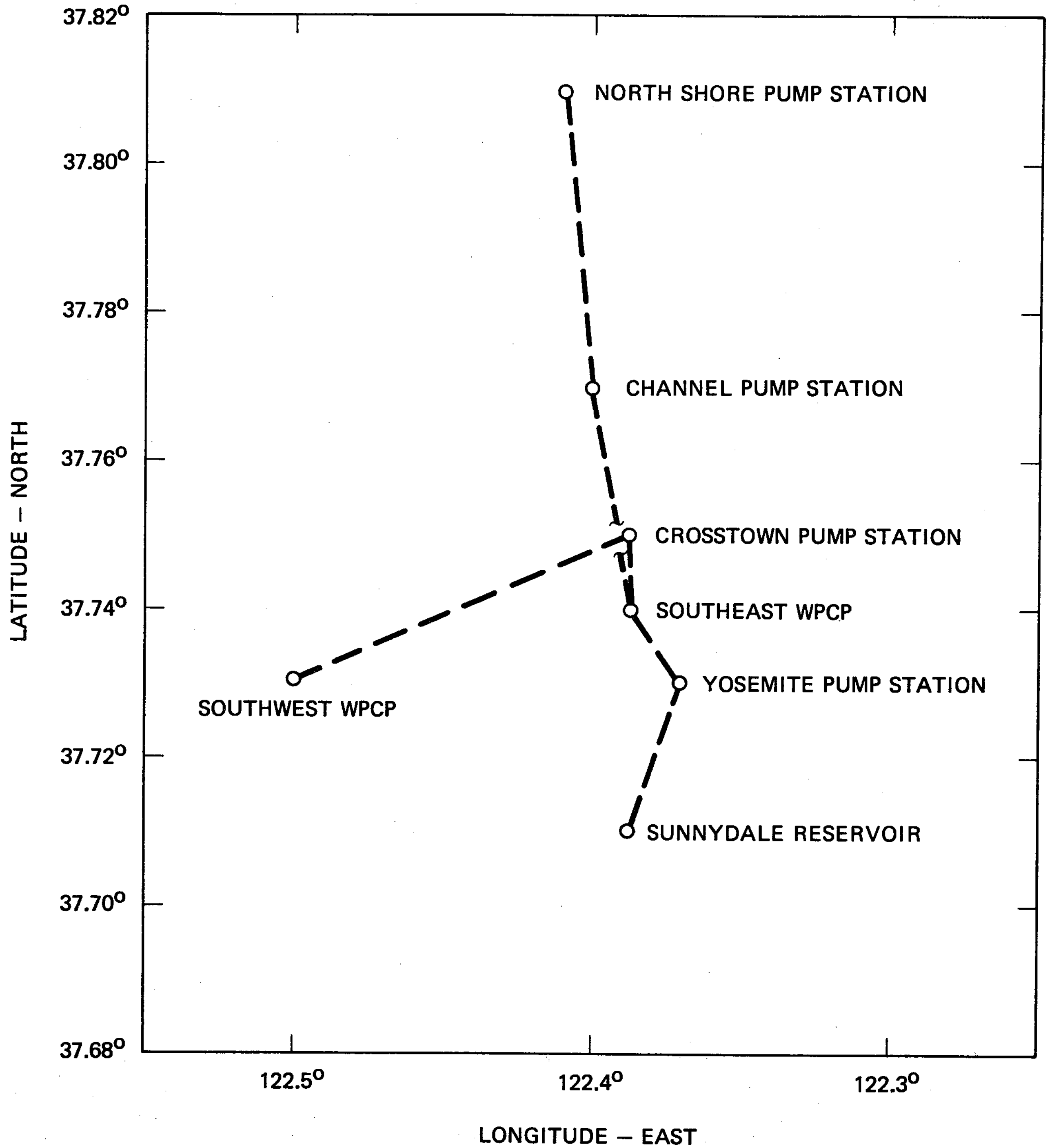


Figure 5-1 Complete Landline Communication Network Utilizing Fiberoptics

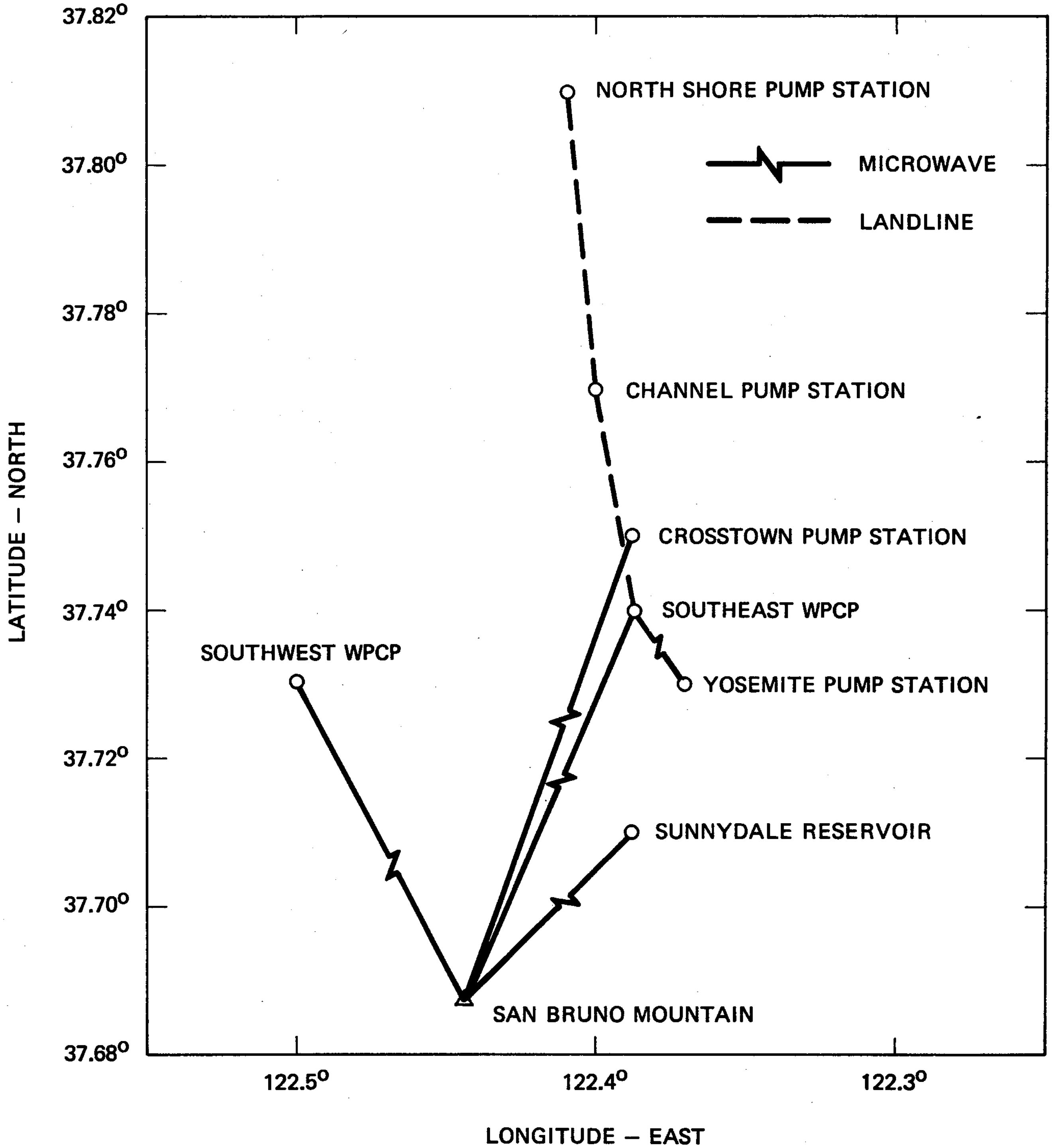


Figure 5-2 Combination Microwave/Landline Communication Network

its implementation would have to be deferred pending a license from the FCC. The entire licensing process, including the preparation of the necessary documents required by the FCC, could conceivably take as much as 18 months. Any unanticipated additional delays or denial of the license by the FCC would adversly impact the implementation and operation of critical communication links.

Because of the above concerns regarding the microwave systems, it appears that the only prudent choice is to select the complete fiberoptic network as the apparent best alternative, even though it is economically not as attractive as the combination microwave/ landline alternatives. The use of fiberoptics for data communication is growing and it is quite likely that this rapidly developing technology would actually cost less in the future.

In addition to the fiberoptic system as a primary communication link, the telephone company leased circuit (type 3002C2) is recommended as a back-up link for major facilities because of its very low costs and independent routing. All other facilities can be adequately served by telephone link only, except for raingage terminals for which a UHF radio system is significantly cheaper.

CHAPTER 6

ALTERNATIVE CONTROL PHILOSOPHIES AND CONFIGURATIONS

This chapter identifies the available control philosophies and system configurations that can be used to process the acquired data and perform the control functions in accordance with system objectives. The cost-effective analysis and the details of the apparent best control system are discussed subsequently in Chapters 7 and 8, respectively.

CONTROL PHILOSOPHIES

The design of the control systems for the North Shore Pump Station, Channel Pump Station, and Southeast WPCP has anticipated, to some extent, the use of a master computer system at the Southeast Water Pollution Control Plant (WPCP) for control of these facilities. This computer system would allow the flow regulation at discrete facilities independent of the local criteria. In other words, the operation of the various remote equipment would be subject to on-line adjustments by the master computer in order to attain the overall performance objectives of the entire system. For example, if the various pump stations contributing flow to the Southeast WPCP are operated based on this concept, they will be regulated so that the sum of flows from all pump stations does not exceed the available treatment capacity at the Southeast WPCP. The relative flow contribution from each pump station could be biased based on such factors as available storage, upstream and downstream sewer levels, priority of overflow locations, and the like. Similarly, predictive data based on the use of rainfall runoff modeling may also dictate the flow from each pump station.

In summary, since the master computer system will have access to data from all facilities, it can base its control decisions not just on local conditions, but rather on conditions throughout the hydraulic network.

All centralized control systems perform a number of separate functions. The most basic of these is "process interface." The process interface accepts contact closures, representing equipment status and alarms. It also accepts analog or digital transmission signals representing process variables such as wet well levels, and conversely, provides contact closures and analog transmission signals for control of process equipment such as pumping units. The operator interface provides a means for operators to communicate with the centralized control system. The control system must also process alarms and provide audible and visual warning of abnormal conditions either at remote facilities or within the control system itself. Centralized control systems can also be programmed to provide control of remote facilities by programming the various computers to automatically produce outputs in response to the various inputs.

Two control philosophies for implementing the control decisions by the master computer system are described below.

Direct Control

Direct control implies that mechanical equipment at remote facilities is connected directly to a central controller without any intervening logic. For example, under this philosophy, the master computer at the Southeast WPCP will generate a proportional signal as some function of the wet well levels at the remote pump stations to directly control the pump speeds at those locations.

Direct control enlarges the data network requirements, since data links must be made to each piece of remote equipment under direct control. This philosophy also tends to place excessive demands on the communication network and mandates very high communication speeds. Further, because the entire control system depends upon one control device, its failure can disable all processes. High speed redundant communication links, elaborate dual computers, and other backup schemes can alleviate some of these concerns, but then the costs of the system become excessively high.

Because of the above reasons, the direct control of the entire wastewater facilities by a master computer at the Southeast WPCP is not recommended. However, for some cases, particularly isolated facilities for which there is no locally implementable control strategy, direct control from a central controller will be necessary. This will provide a simpler flow prioritization and flushing operation and eliminate the need for local controllers.

Supervisory Control

Supervisory control implies that instead of directly controlling remote facilities, instructions are issued to a local controller which then controls the operation of the related mechanical equipment. This mode of operation does away with the major problems just described for the direct control system, in that the bidirectional data transmission needs between the process and supervisory controller are substantially reduced, resulting in a much simpler data communication network. Furthermore, in case of supervisory system malfunction or loss of communication, the local controllers readily take over and continue to exercise routine controls based upon the last command received from the supervisory system. The redundant communication links are, therefore, not essential. It should be noted that the hydraulic optimization of various interacting physical facilities may not be fully realized in case of supervisory controller malfunction; however, since the critical local controls continue to operate, the results are not catastrophic.

CONTROL SYSTEM CONFIGURATIONS

The City and County of San Francisco divides naturally into two major drainage basins, the bay side and the ocean side. These drainage basins are further divided into a number of smaller subbasins. When the construction of the physical system elements is completed, each of these subbasins will contain some form of storage and transport facilities for combined wastewater storage and delivery of both dry and wet weather to the two treatment plants--the Southwest and Southeast WPCPs.

There are several supervisory control configurations that can be structured to manage the flows within each subbasin. The three basic configurations that appear to be the best candidates for further evaluation are a fully distributed configuration, a semidistributed configuration, and a centralized configuration. All three configurations provide a separate operating station for each of the two major drainage basins and an overall operating station for the entire City.

Fully Distributed Configuration

The fully distributed configuration is based upon a three-level control hierarchy as shown on Figure 6-1. The first level in this heirarchy is a supervisory control center (SCC) to be located at the Southeast WPCP. The second level consists of two area control centers (ACCs), one for the ocean side and the other for the bay side of the City, located at the Southwest and Southeast WPCPs, respectively. Both the first and second levels would be implemented with minicomputers. The third level consists of remote terminal units (RTUs) and telemetry stations located in various remote facilities. Remote terminal units are microcomputer based and are capable of executing limited control logic independent of level 1 and level 2 computers. Telemetry stations, however, are capable only of accepting inputs and providing outputs under direct control of the level 1 or level 2 computer.

The SCC computer system and its peripheries (accessories) are shown in greater detail on Figure 6-2. Major peripheries include a color graphic cathode ray tube (CRT) operator interface, logging typers, a printer for report generation, and a magnetic tape unit for long-term data storage. The principal purposes of the SCC computer are the support of the operator interface, alarm and event logging, report generation, and execution of any predictive hydraulic model programs.

The details of the ACC computer systems are shown on Figure 6-3 and include a typer for alarm and event logging and an alphanumeric CRT for operator interface. The ACC computers will control data communication with the remote facilities and will execute control

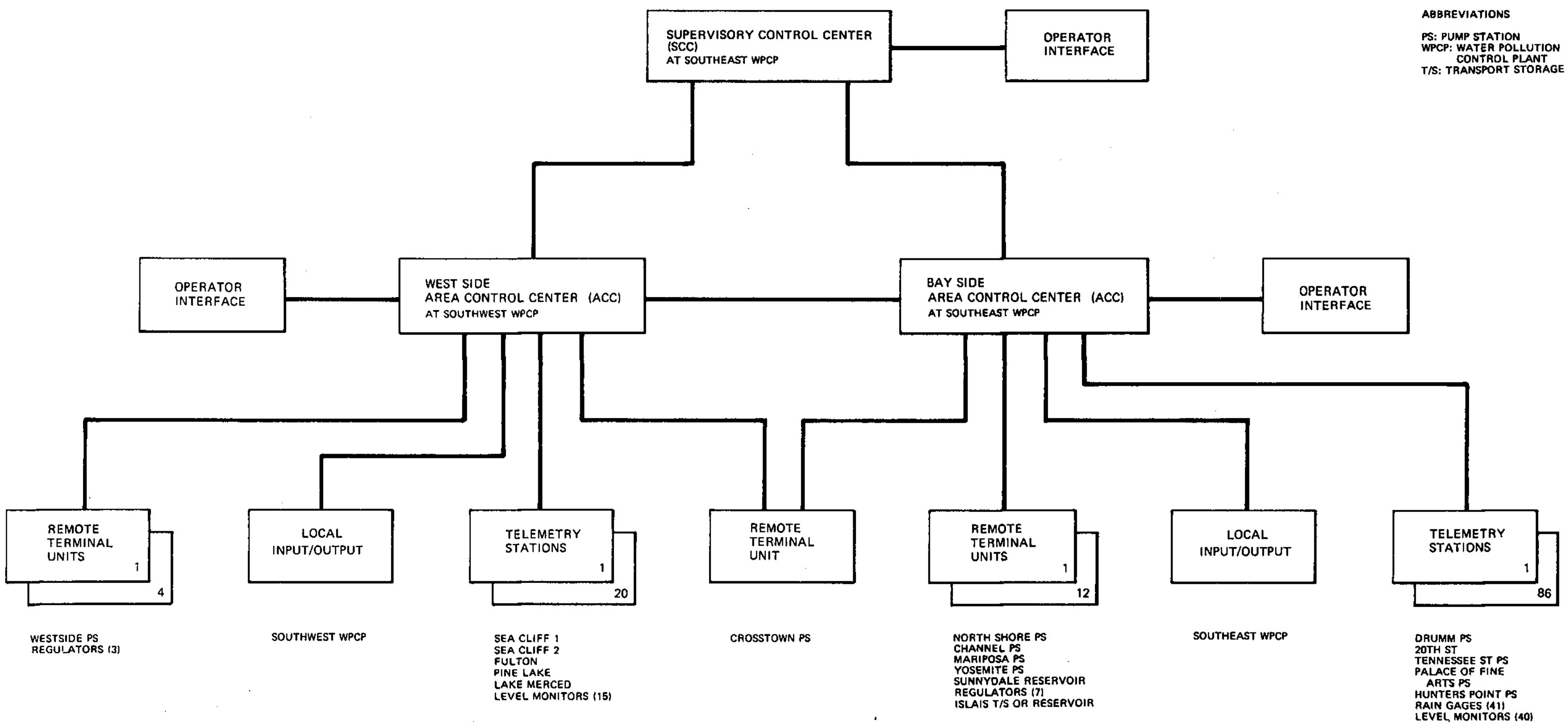


Figure 6-1 Fully Distributed Configuration

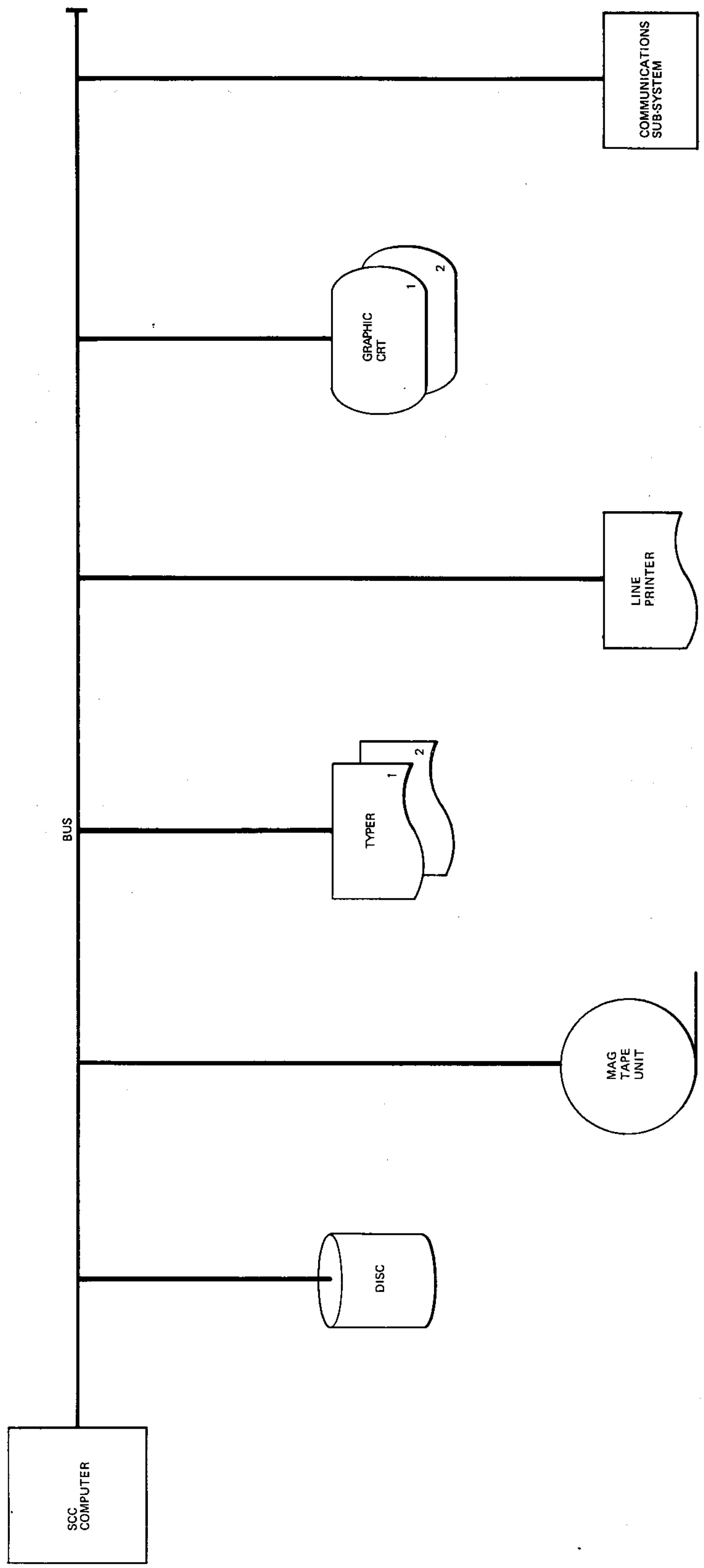


Figure 6-2 Supervisory Control Center Computer System

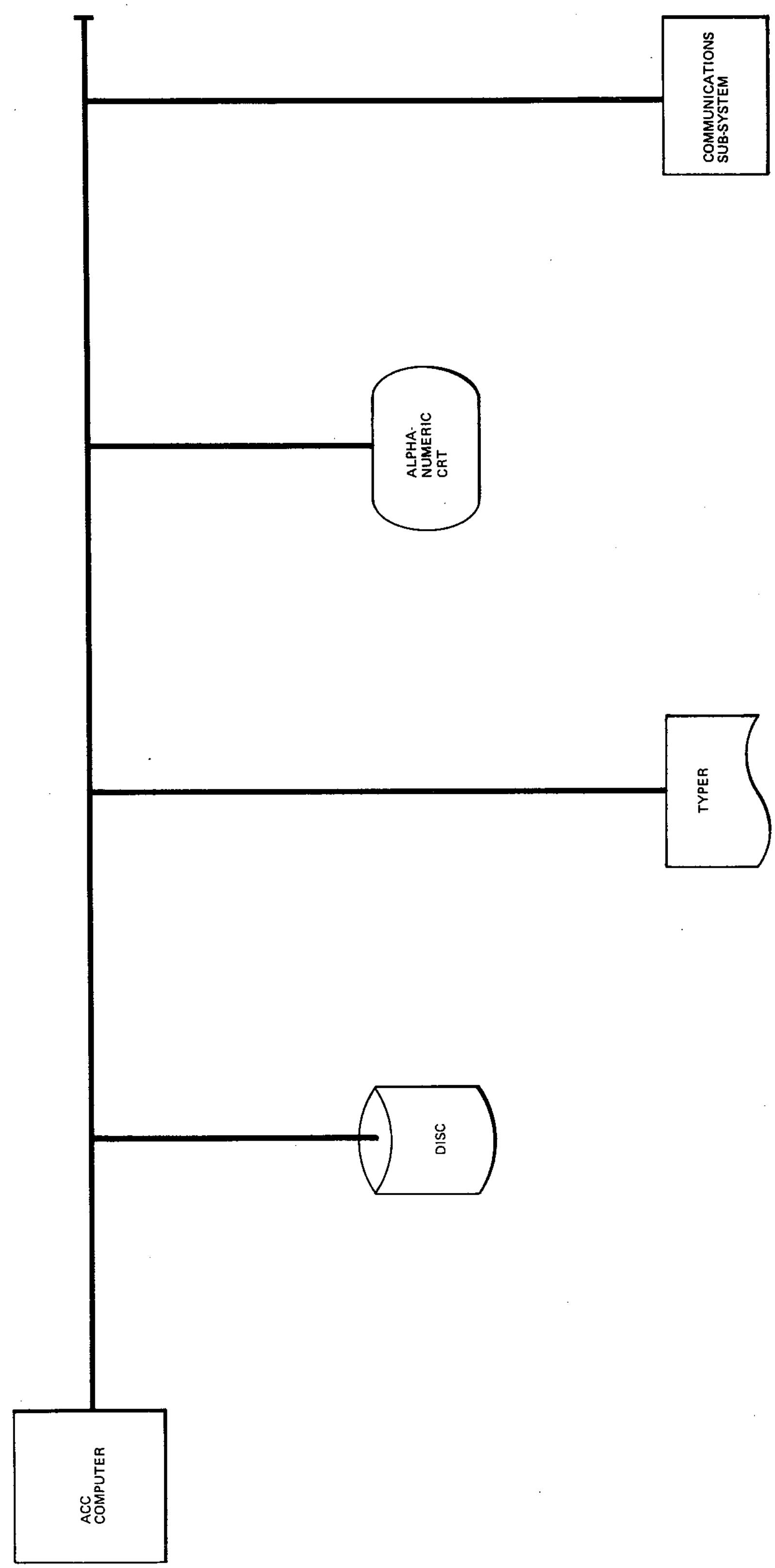


Figure 6-3 Area Control Center Computer System

strategies where required. The ACC computer will also process alarms, provide status monitoring, and permit manual control of their related facilities.

RTUs will be provided at the major remote facilities listed on Figure 6-1. RTUs provide process interface, implement commands from the ACCs, and execute local control algorithms. RTUs are not provided with an operator interface. This function is normally provided by a local control panel with conventional indicators, annunciators, switches, and backup control stations. Process interface functions at the Southeast WPCP and the Southwest WPCP that normally would be provided by RTUs will be absorbed by the ACC computer.

Telemetry stations provide process interface and response to communications from the ACC. These units are used at facilities where control functions are not required or where it is acceptable to execute all control logic in the ACC and transmit the commands to the telemetry station. Telemetry stations will be used at small pump stations, isolated gate structures, raingages, and similar locations.

The fully distributed configuration separates essential communication and control functions from the main operator interface and report generation functions. This ensures that no conflict for computer processing time will occur. It also provides some protection from a catastrophic system failure since each computer operates independently of the other. Failure of a single computer will cause the loss of some functions, but many remaining functions can continue normally, reducing the impact on operations. Two features of the proposed configuration should be noted: first, an inter-ACC link is provided to permit direct transfer of essential data between ACCs without depending on the SCC; second, the Crosstown Pump Station RTU is connected to both ACCs permitting direct control and monitoring of this critical facility from either ACC. The Crosstown Pump Station will normally be monitored and controlled by the bay side ACC. Transfer to the west side ACC can occur if the bay side operator relinquishes control or if the bay side ACC computer fails to update a timer at the Crosstown Pump Station.

Semidistributed Configuration

A variation of the fully distributed configuration, described above, is to eliminate the bay side ACC computer and transfer all of its functions to the SCC computer. This approach stems naturally from the fact that both computers are to be located at the same site, and most likely within the same control room at the Southeast WPCP. Figure 6-4 depicts this configuration.

The elimination of the bay side ACC computer simplifies the communication network. This configuration, however, increases the processing load on the SCC computer which is a significant

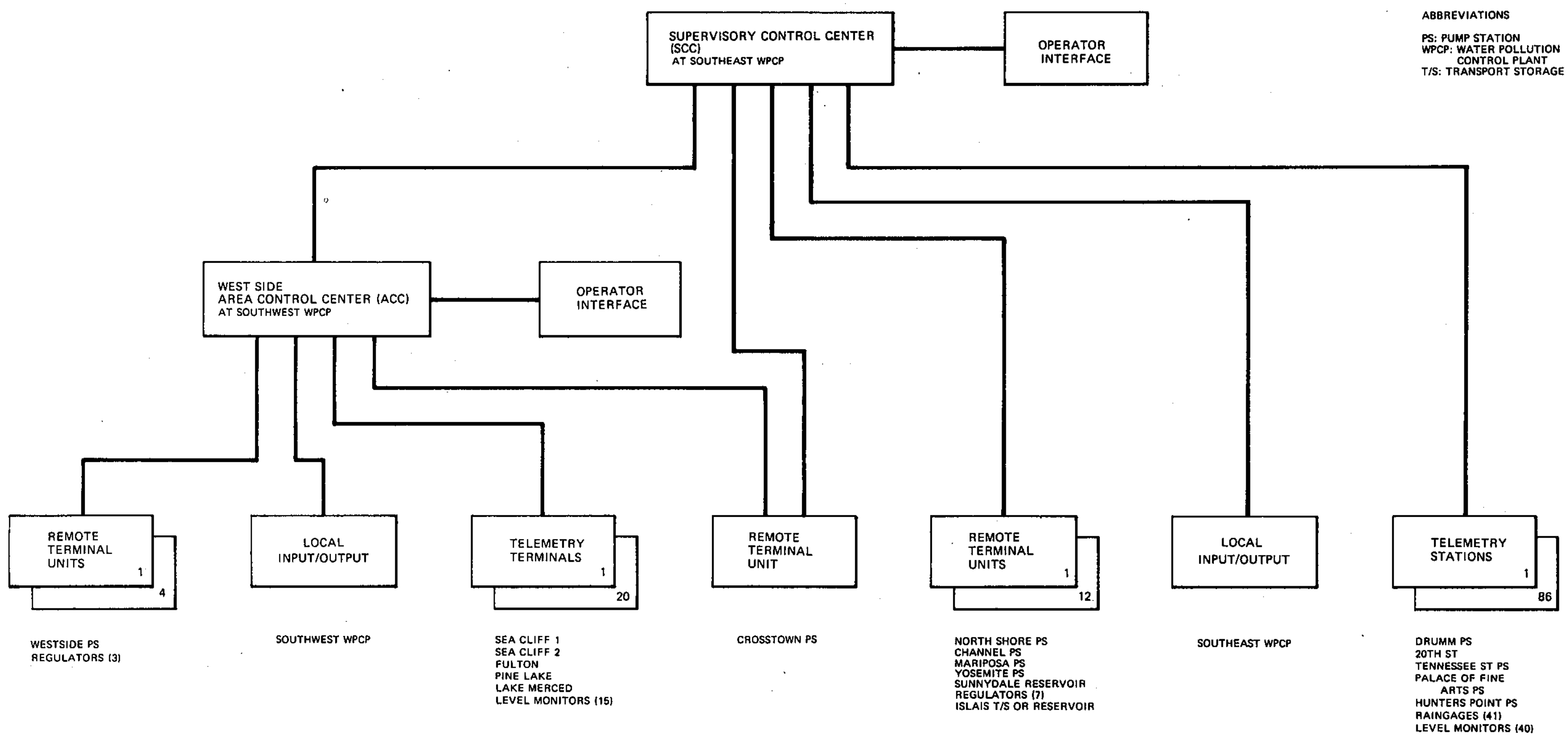


Figure 6-4 Semi-Distributed Configuration

disadvantage, particularly if a very complex hydraulic model is implemented. Like the fully distributed system, the semi-distributed configuration divides the system into two distinct subsystems which are essentially independent of each other. A failure of the bay side system will not affect the operations of the ocean side system and visa versa. Likewise, the Crosstown Pump Station is interfaced to both the bay side and ocean side systems providing redundancy for this critical station.

Centralized Configuration

The centralized configuration, as shown on Figure 6-5, eliminates both ACC computers and transfers all of their functions to the SCC computer system located at the Southeast WPCP. RTUs and telemetry stations are unchanged except that an RTU must be added at the Southwest WPCP in order to provide process interface at that location. A dual computer system, as shown on Figure 6-6, is used for the SCC in order to increase the reliability of this system since failure of the SCC computer system would result in total failure of the entire supervisory control system.

In this configuration the SCC computer supports operator interfaces at both the Southeast WPCP and Southwest WPCP. Because of the added process loading, software for this type of system is significantly more complex than either of the distributed configurations, and greater reliance is placed on communication links for operation of the west side system. These factors will affect the reliability of the centralized system adversely; and therefore, it will likely be less reliable than the distributed systems.

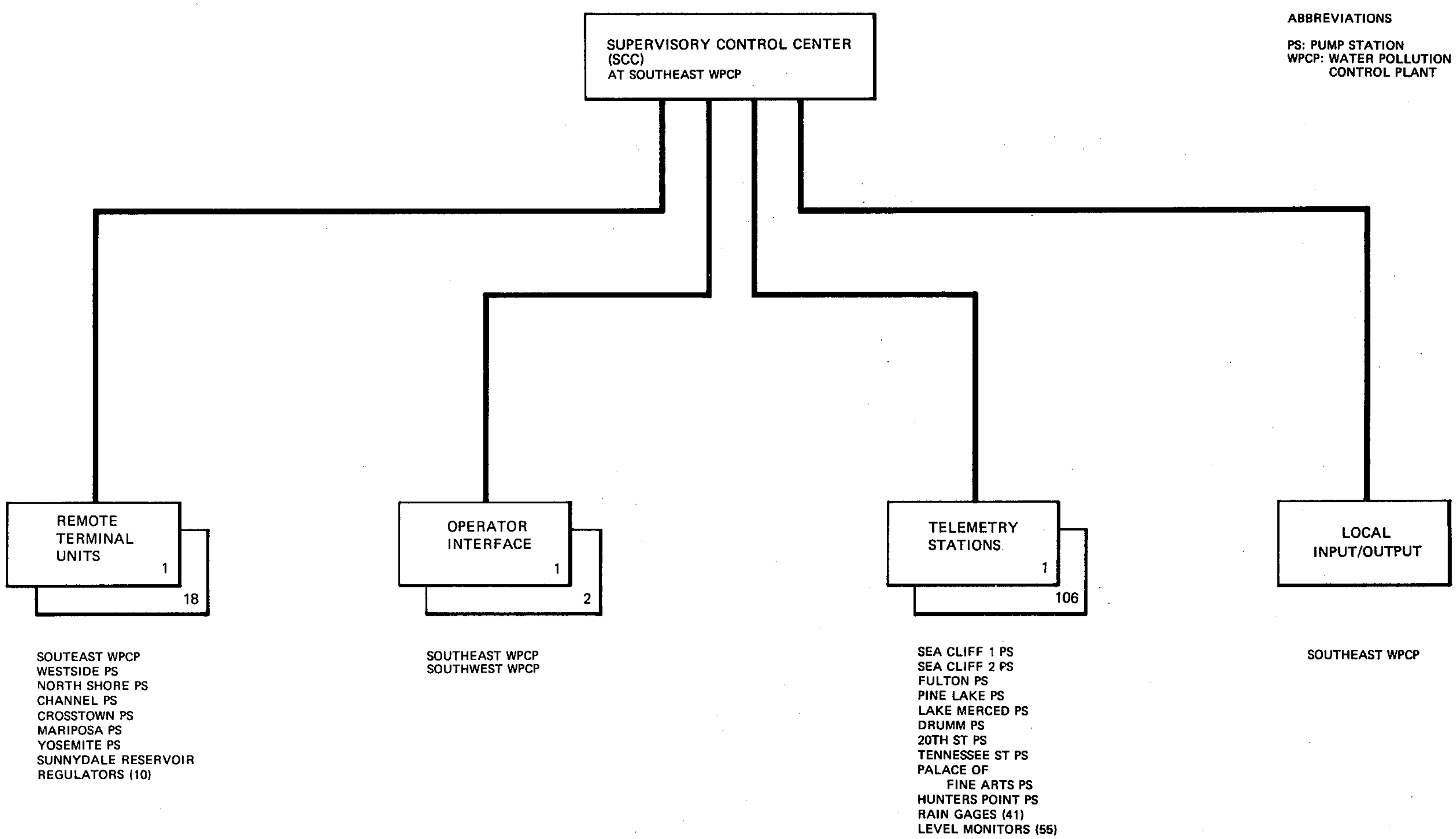


Figure 6-5 Centralized Configuration

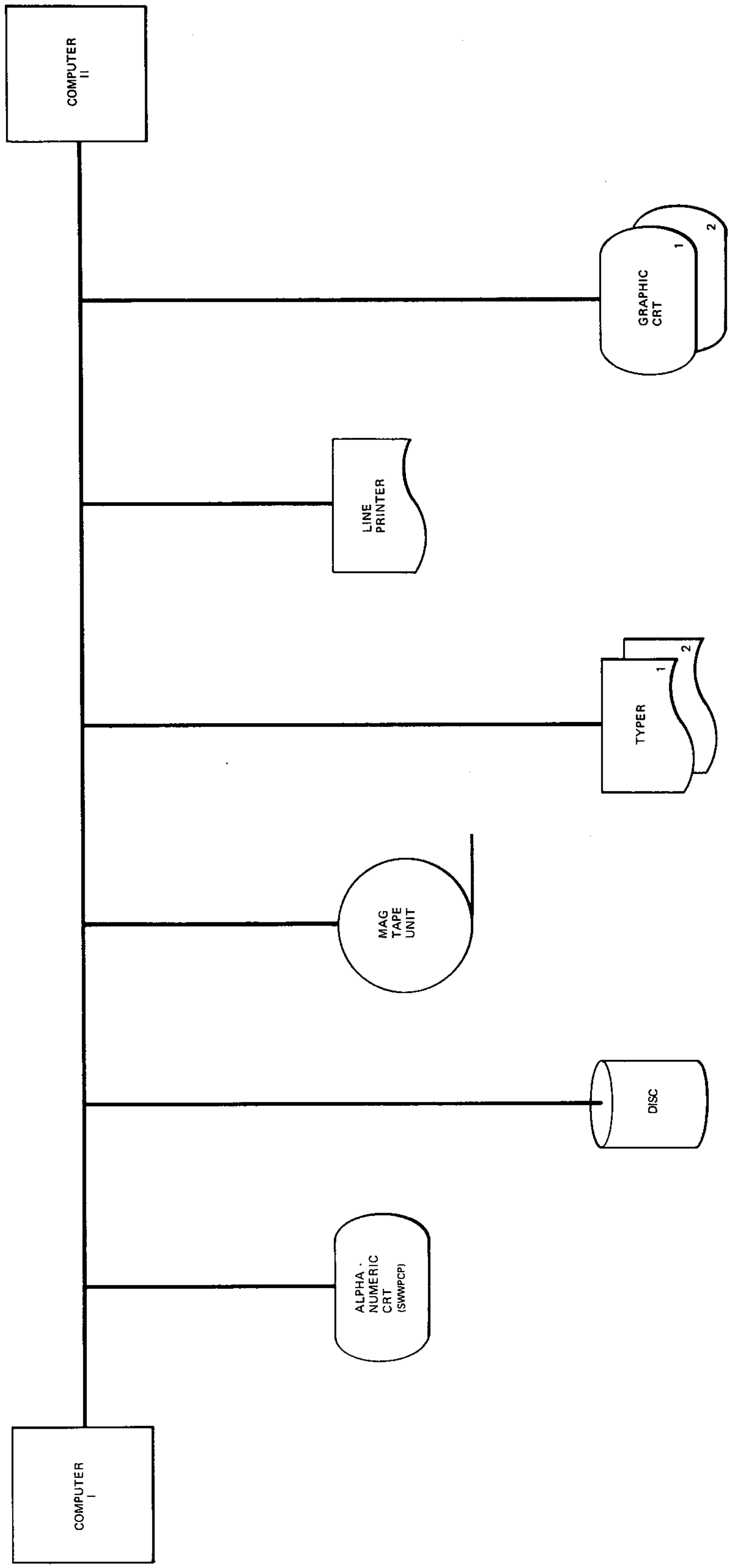


Figure 6-6 Supervisory Control Center Computer System for Centralized Configuration

CHAPTER 7

COST-EFFECTIVENESS ANALYSIS

In order to assure a uniform base for monetary cost comparisons, the three alternative control configurations, described in Chapter 6, have been structured to be functionally equivalent. The performance characteristics of these alternatives, nevertheless, vary to some degree. Therefore, in order to draw meaningful conclusions regarding their desirability, both monetary costs and related nonmonetary factors must be considered.

MONETARY COSTS

The monetary costs of the three alternative control configurations are compared in Table 7-1. The cost comparisons are based upon the estimated number of field terminal units (FTUs) associated with the supervisory control system. Since the remaining cost factors such as transmission network costs, process sensor costs, and local instrumentation and control costs are the same for all alternatives, they are not included in this table. Furthermore, these comparisons are based solely on the capital costs, since the operation and maintenance (O&M) costs are estimated to be roughly the same for all alternatives. This is because of the fact that in a computer based instrumentation and control system most of the maintenance costs are typically associated with the process sensors which would essentially be the same for all three alternatives.

As shown in Table 7-1, the cost differences between the three alternatives are rather small. The fully distributed system places the lowest demands on the supervisory control center (SCC) computer which, therefore, is the least expensive. Under the semidistributed option, the SCC computer must perform area control center (ACC) tasks for the bay side system; this requires a larger, more expensive machine. The centralized system places even higher loading on the SCC computer and, in addition, reliability mandates a dual computer system. The extra hardware and software required for dual computer systems makes the centralized SCC somewhat more expensive than either of the other options.

Conversely, software is the least expensive for the centralized system, because ACC related programming requirements for the other alternatives are not applicable to this alternative. Installation and start-up is directly related to the amount of equipment involved and is therefore least for the semidistributed configuration.

Table 7-1. Estimated Capital Costs, Alternative Control Configurations - ENR 3800

Quantity	Item[a]	Capital costs, dollars[a]		
		Fully distributed configuration	Semidistributed configuration	Centralized configuration
1	Supervisory control center (SCC)[b]	100,000	150,000	325,000
2	Area control center (ACC)[b]	120,000	-	-
1	Area control center (ACC)[b]	-	60,000	-
17	Remote terminal unit[c]	425,000	425,000	-
18	Remote terminal unit[c]	-	-	450,000
41	Telemetry terminal (at raingages)	100,000	100,000	100,000
65	Telemetry terminal (general service)	140,000	140,000	140,000
1	Software (for SCC and ACC)	280,000	280,000	230,000
-	Hardware and software subtotal	1,165,000	1,155,000	1,245,000
-	Installation, startup, debugging, etc. (100 percent of above)	1,165,000	1,155,000	1,245,000
-	Subtotal	2,330,000	2,310,000	2,490,000
-	Engineering and contingencies (35 percent)	815,000	809,000	872,000
-	Total costs	3,145,000	3,119,000	3,362,000

[a] Refer to Appendix F for model numbers of equipment used for price estimating. All costs are based upon Engineering News-Record Construction Cost Index of 3800 (January 1980).

[b] Based upon process input and output count from Appendix D with 100 percent expansion capability.

[c] Includes estimated software costs.

As Table 7-1 shows, the semidistributed system is the least expensive alternative on a total capital costs basis. The cost difference between the three alternatives, however, are too small to judge their desirability simply on capital cost comparisons.

NONMONETARY FACTORS

Table 7-2 compares the inherent differences between the nonmonetary factors of the three alternative control configurations. The set of factors presented in this table relate generally to operational flexibility and reliability, which are important considerations in selecting the apparent best alternative. These factors are rated on a scale of 1 to 3 with decreasing order of desirability; i.e., a rating of 1 signifies the most desirable factor.

Table 7-2. Nonmonetary Factors, Alternative Control Configurations

Factor	Fully distributed configuration	Semi-distributed configuration	Centralized configuration
Ease of Maintenance			
Hardware	1	1	2
Software	1	2	1
Expansion potential	1	2	3
Reliability	1	2	3
Manpower requirements	1	1	1
Compatibility with existing design	1	1	1
Process monitoring and control capability	1	1	1

Note: "1" is most desirable; "3" is least desirable.

As shown in Table 7-2, the ease of hardware maintenance is rated lowest for the centralized system. Typically, hardware maintenance requirements are directly proportional to the amount of hardware in the configurations. The centralized system requires a significantly larger computer system at the SCC and, therefore, has somewhat higher maintenance requirements than the two distributed systems. Software maintenance is rated most difficult for the semidistributed system because procedures are inherently different between the bay side and ocean side systems.

The expansion potential is rated higher for the fully distributed system because computation load is divided between separate SCC and ACC computers. In this configuration, the SCC is very lightly loaded, and significant expansion will not cause severe impact. At the ACC level, however, expansion is more limited, but provision can be made in the design to add ACCs in the future if major expansion is contemplated.

Reliability is rated best for the fully distributed system because failure of any one computer disables only a portion of the system. For example, if the SCC fails, the ACCs continue to maintain communication with all remote facilities. Similarly, if an ACC fails, only the remote facilities monitored by that ACC will lose communication. In the centralized system, however, the failure of the central computer will result in total disruption of the control system. The dual computer system reduces the amount of failure time expected, but the impact of a failure remains the most severe.

Manpower requirements should be the same for all three options. However, under the fully distributed option there would be an extra cathode ray tube (CRT) located in the Southeast Water Pollution Control Plant console. This CRT would be operated either by the SCC operator or, if necessary, an extra operator responsible only for the bay side system could be utilized. The need for a bay side operator is more dependent on the overall work load of the SCC operator than on any conceivable requirements of the supervisory control system.

Interface requirements to remote facilities are exactly the same for all three; therefore, the compatibility with existing design is rated equal. Similarly, all three alternatives are equally capable of performing the anticipated monitoring and control functions and, therefore, are rated equal in this category.

Review of Tables 7-1 and 7-2 eliminates the centralized control alternative not only because of its higher capital costs, but also because of the nonmonetary operational disadvantages. The fully distributed and semidistributed alternatives cost essentially the same, but as is apparent from Table 7-2, the fully distributed system has a definite operational edge. Furthermore, a fully distributed system will tend to encourage a more responsive role from the bay side and ocean side ACC operators, principally because of their clearly defined duties.

Because of the above reasons, the fully distributed configuration is selected as the apparent best control alternative. Chapter 8 discusses the specifics of this alternative in greater detail and provides appropriate cost data.

CHAPTER 8

APPARENT BEST CONTROL SYSTEM

In this chapter, the apparent best control system for citywide flow management is described in terms of system arrangement, specific functions, design concepts, software requirements, costs, and procurement procedures. The recommendations on interim controls and the interface requirements for local controls are also discussed. Major factors considered in arriving at the recommendations were discussed in the previous chapters.

SYSTEM ARRANGEMENT

As shown on Figure 8-1, the apparent best control system is based upon the fully distributed control configuration which uses a three-level hierarchy arranged from top to bottom as follows:

1. Supervisory Control Center (SCC)

2. Area Control Centers (ACCs)

3. Field Terminal Units (FTUs)

These three levels are considered part of the integrated Citywide Supervisory Control and Data Acquisition (SCADA) system. A fourth level, namely local control center, is also an essential part of the SCADA system. This level is provided as part of the physical facility, however, since the design of the local control system depends principally upon the local instrumentation and control needs as perceived by the facility designers. The examples of local controls are the control systems for the Channel and North Shore Pump Stations.

Also included in the SCADA system is a communication network which interconnects the various hierarchical levels. Communication network options and recommendations were discussed in Chapter 5.

SYSTEM FUNCTIONS AND DESIGN CONCEPTS

Within the three-level hierarchy described above, the SCC and ACCs are minicomputer-based systems while the FTUs are microcomputer-based systems. The functions of each of these levels and some design concepts are described below.

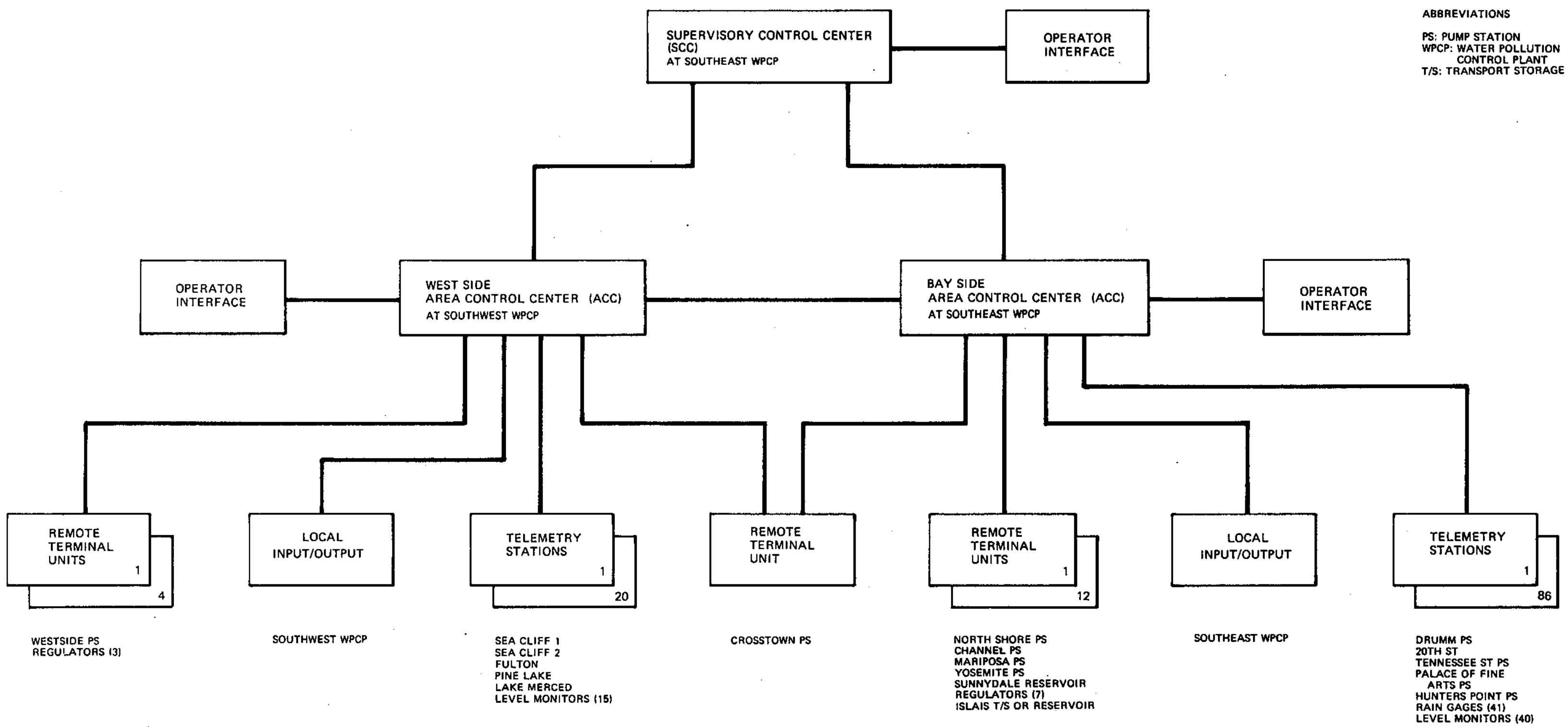


Figure 8-1 Apparent Best Control System

Supervisory Control Center (SCC)

The SCC will be located at the Southeast Water Pollution Control Plant (WPCP). The specific functions of the SCC are as follows:

1. Control communications with ACCs.

2. Store status of all discrete inputs.

3. Store values of all analog inputs and pulse inputs.

4. Process SCADA system alarms, selected facility alarms, and alarms not acknowledged by ACC operator within 30 seconds (adjustable).

5. Execute predictive control strategy.

6. Generate daily and monthly reports.

7. Support operator interface.

8. Transmit data and commands to ACC's.

As shown on Figure 8-1, the SCC is connected to each ACC via a high-speed communication link. This permits rapid data transfers between the control centers (approximately 0.25 milliseconds/ discrete and 3.2 milliseconds/analog). Transfer of all data collected by ACCs to the SCC is not necessary since detailed status of most equipment is not required by the SCC operator. However, the selection of specific data for transmission requires significant computer processing time and complex software. Therefore, it is recommended that all data that is collected by the ACCs should also be transmitted to the SCC. This approach has an added advantage in that it permits the ACC to be left unmanned during dry weather.

Appendix D contains a suggested grouping for alarms from various remote facilities. These alarms should normally be processed at the ACC level. However, for additional flexibility the SCC should also be capable of processing these alarms if they are not acknowledged by an ACC operator within 30 seconds.

The predictive control strategy, described in Chapter 4, will be executed by the SCC. This control strategy requires extensive computational capability, and the necessity to execute this strategy in real time will dictate the capacity of the SCC computer.

The SCC computer should also generate daily and monthly reports of system operation. These are essentially the summaries of significant transport/storage and pumping systems operations, along with the duration, frequency, and volume of overflows. Considerable data processing capacity is required to generate such reports. However, since report generation is generally not time critical, this task should run at a lower priority than the control strategy indicated above. This will permit the same computer capacity to be used for both tasks. Delays may result in obtaining reports during storm conditions, since the predictive model will essentially be using all available computer capacity.

The SCC computer supports the main system operator interface. This interface will utilize interactive color graphic cathode ray tubes (CRTs). These CRTs display all equipment on graphic diagrams of the system. This permits the operator a ready access to input/output points by simply positioning a cursor within a target for the equipment for which data or control is desired, thus eliminating the need for remembering and keying in abstract equipment identification numbers.

Area Control Centers (ACCs)

Two ACCs are proposed for the citywide SCADA system, one to be located at the Southeast WPCP to serve the bay side, and the other to be located at the Southwest WPCP to serve the ocean side system. The specific functions of the ACCs are as follows:

1. Control communication with FTUs.

2. Store status of all discrete inputs.

3. Store values of all analog inputs and pulse inputs.

4. Process alarms.

5. Execute reactive control strategies.

6. Support operator interface.

Each ACC is connected to the various FTUs by communication channels. The ACC periodically polls the various terminals for their data and stores these data in its memory. It also checks incoming data for alarm conditions. If an alarm condition occurs, the ACC will log the alarm, generate an audible signal, and display the alarm on the CRT. Upon request, the ACC transmits analog and discrete input data to the SCC.

Control strategies that are too complex for execution by the FTUs, or those that may need frequent modification, are executed by the ACC. When control strategies are executed by the ACC, output commands are transmitted to the appropriate FTU, which then controls the mechanical equipment in the specific remote facility.

Field Terminal Units (FTUs)

As shown on Figure 8-1, two types of FTUs are proposed: namely, remote terminal units and telemetry terminals.

FTUs convert status and analog inputs into digital data and transmit these data to the ACC on request. FTUs also receive digitally coded commands and values from the ACC and convert these to outputs. Both types of FTUs provide the following inputs and outputs:

1. Discrete Input (DI or DA) monitors the status of dry contacts representing equipment status (DI) and alarms (DA).

2. Pulse Input (PI) counts dry contact closures from devices such as raingages.

3. Discrete Output (DO) provides a momentary dry contact closure for control of field equipment such as pumps, gates, etc. Contact closure duration is adjustable from 0.5 to 5.0 seconds.

4. Analog Input (AI) accepts 1- to 5-volt or 4- to 20-milliampere analog signals representing process variables such as flow level.

5. Analog Output (AO) provides a 4- to 20-milliampere analog signal for control of process equipment such as pump speed control.

In addition to the above input/output functions, RTUs are also capable of executing limited control logic. For example, an RTU could readily handle pump sequencing and pump speed control in response to suction well level. This arrangement is particularly attractive since supervisory control commands are accomplished completely within the RTU microcomputer eliminating the need for extra process interface points. RTUs utilize the same process inputs for both control and data transmission to the ACC. In addition, they use relatively small microcomputers to accomplish their logic. This precludes the use of convenient programming languages such as FORTRAN or BASIC, and computer programmers are required to write or modify RTU control programs.

Some design details for loads to be operated by field terminal units are given in Appendix G, Transient Suppression.

SYSTEM CAPACITY

Digital SCADA systems are inherently capable of handling large data bases very efficiently. Appendix D lists a proposed initial data base. It is recommended that the system should be designed with 100 percent expansion capability both in point count and in remote terminal count. Expansion capacity should be provided in two forms. The bulk of it, three-quarters, should be provided in the form of card file space, power supplies, and software capacity for future plug-in field interface cards. The smaller portion, one-quarter, should include the plug-in field interface cards for immediate use.

SOFTWARE REQUIREMENTS

A number of software programs are required by the SCADA system computers in order to implement the citywide control functions. Programs which are basic to system operation, such as data transmission, will require no modifications during the life of the SCADA system. Such programs can be written in machine language or in assembly code. Other programs, such as process control, will require frequent modifications. These programs must be written in a high level language, such as FORTRAN. The following paragraphs discuss some of the programs which will be required by the SCADA system.

Operating System

The operating system is the basic program which schedules all other jobs in the computer and controls the various peripheries. The operating system for the SCC and ACC computers must support disc memory, real time, and multiprogramming. This type of operative system assigns a priority to all processing requests including requests which are generated within the computer as a function of elapsed time since the last execution.

Application Programs

Application program requirements are tabulated in Table 8-1 and are briefly described below.

Table 8-1. Application Program Requirements

Number	Application programs	SCC	ACC	RTU	Telemetry terminals
1	Data aquisition and control (DAC)			X	X
2	Alarm processing (ALARM)	X	X		
3	Communication control (COMM)	X	X		
4	Control strategy execution (CNTL)		X	X	
5	FORTRAN	X			
6	Report generation (REPGEN)	X			
7	Operator interface (OPTIFC)	X	X		
8	Graphic display generation (GRAPHIC)	X			
9	Data/event logging (LOG)	X	X		
10	Diagnostics (DIOG)	X	X	X	X

Data Acquisition and Control (DAC). The DAC program controls the input/output multiplexers, analog to digital converters, and digital to analog converters as required to transfer field data into the SCADA system and commands out of the SCADA system.

Alarm Processing (ALARM). The ALARM program checks all process inputs for possible alarm conditions. Any discrete input can be defined as an alarm for either the true or the false state. Analog inputs are checked for high, low, high-high, low-low, and high rate of change. The ALARM program also continually monitors the SCADA system itself for possible malfunctions.

Communication Control (COMM). The COMM program controls the transfer of data between the FTUs, ACCs, and SCC. Included in this task is checking data transfers for errors and discarding any data transfer that contains an error.

Control Strategy Execution (CNTL). This is a high level process control language. This langauge is built around software subroutines which represent common conventional control elements. This permits control engineers to readily create new strategies or modify existing strategies without the need to call computer programming specialists.

FORTRAN. FORTRAN is a common high level engineering language suitable for calculations and modeling problems.

Report Generation (REPGEN). The REPGEN program is a high-level report generator that facilitates assembling of historical data into daily and monthly reports.

Operator Interface (OPTIFC). The OPTIFC program supports the operator interface. This program permits the operator to monitor engineering unit data and status and to execute control.

Graphic Display Generation (GRAPHIC). The GRAPHIC program is an enhancement of the OPTIFC program for the SCC which generates schematic diagrams of the citywide system, annotates these diagrams with values and status, and permits the operator to identify field equipment for control by moving a cursor to appropriate targets on the schematic diagrams.

Data/Event Logging (LOG). The LOG program prints alarms, significant operator actions, and SCADA system events on the typers.

Diagnostic (DIOG). The DIOG program consists of both on-line and off-line programs which test the SCADA system for proper functioning. On-line programs run periodically under the control of the operating system and generate suitable alarms in case of a failure within the SCADA system. Off-line programs must be loaded by maintenance personnel and are used primarily as a servicing aid.

CONTROL SYSTEM COSTS

An estimate of the overall costs for the Apparent Best Control System is presented in Table 8-2. As shown in the table, the cost components include the fully distributed control system costs, the data communication network costs, and the incremental costs for predictive control (rainfall forecasting and use of the forecasts). As noted previously, the predictive control system should be developed in several stages. The costs for later stages will depend on results with introductory predictive control. Estimates of the later stages are in the table so that the totals include all costs for citywide control, as well as can be estimated at present.

Table 8-2. Estimated Overall Costs for Apparent Best Control System--ENR 3800

Component	Costs, dollars[a]			
	Capital	Annual operation and maintenance	Present worth	Equivalent annual
1. Fully distributed control system	3,145,000[b]	528,000[c]	8,684,000	828,000
2. Data transmission network	716,000[d]	20,000[e]	926,000	88,000
3. Incremental cost for predictive control				
a. Initial recommendation[f]	283,000	31,000	608,000	58,000
b. Future additional items[g]	620,000	201,000	2,728,000	260,000
Total	4,764,000	780,000	12,946,000	1,234,000

[a] All costs are based upon Engineering News-Record Construction Cost Index of 3800 (January 1980).

[b] Refer to Table 7-1 for cost breakdown.

[c] Assumes 10 percent of hardware costs for annual maintenance plus two control operators per shift on the average, 7 days a week, for operational costs ($885,000 x 0.10 + $55,000 x 4 x 2).

[d] Refer to Table 5-1 for cost breakdown.

[e] Assumes 5 percent of hardware costs for annual operation and maintenance, ($408,500 x 0.05). These O&M costs should also cover the minor costs for lease of telephone circuits as recommended in Chapter 5.

[f] Costs through Introductory Predictive Control (Control Stage 3). See Tables 4-3 and B-1 for cost breakdowns. These items should be operational at the same time as the Citywide Control System.

[g] Cost allowance for future additional items to improve the accuracy of predictive control (Control Stages 4 and 5). See Tables 4-3 and B-1 for cost breakdowns.

It is emphasized that Table 8-2 presents the costs of the citywide supervisory control and data acquisition system only; it does not include any costs associated with the local instrumentation and control systems or the costs of the various process instruments for data collection at pump stations, reservoirs, and other physical facilities. All such costs will be included in the estimates for the specific physical facilities under consideration. However, the costs for predictive control include the costs of meteorological instruments, such as raingages, which are necessary for predictive control.

As noted in the table, all costs are based upon the January 1980 prices for materials and labor. Both capital and operation and maintenance costs are brought back as present worth costs using a 7-1/8 percent discount rate for the 20-year life of the project. The equivalent annual costs are calculated based upon a capital recovery factor of 0.0953.

PROCUREMENT PROCEDURES

The SCADA system is unlike other construction projects in that it will require work to be performed in a number of facilities which are constructed under several separate contracts. The SCADA system supplier will need a close dialog with the City in order to coordinate the work performed in these facilities. This dialog will also be essential during the software development phase when various programming details must be worked out mutually between the software designer and the City.

While it is possible to procure the SCADA system as a portion of a conventional construction project, there are several disadvantages associated with this approach. Inserting a general contractor in the communication path between the SCADA system supplier and the City will unneccesarily impede communication. Also, typical general contractors are not well qualified to manage computer system construction. They will mark up the costs to cover their overhead and profit, but generally will contribute little to the SCADA portion of the contract. Because of these reasons, it is recommended that the contract documents be structured to procure the SCADA system directly from the suppliers who are experienced in design and installation of the computer systems.

INTERFACE TO LOCAL CONTROLS

Each physical facility will have a local control system which, as a minimum, should permit safe and convenient operation of that facility both manually and automatically. A major problem with the procurement of the SCADA system is defining the interface between the SCADA system and the local controls. To mitigate any potential conflicts, it is recommended that each local control system contractor provide a single terminal strip which carries the entire interface between that facility and the SCADA system. The facility contractor should also test this interface to insure that each pair of terminals carries the specified status or analog value, or responds properly to signals placed on the terminals by the SCADA system. Once these tests are completed, the SCADA system supplier will install his equipment and connect to this terminal strip. The facility contractor must be provided with an input/output schedule for the specific facility in order to accomplish his part of the work. Similarly, the facility design engineer should show these interfaces on diagrams prepared for construction documents.

Existing facilities will require modifications to provide the foregoing interface. As an example, Appendix A contains recommendations for modifying controls for North Shore and Channel Pump Stations, which are essentially the major existing facilities requiring control modifications. The SCADA system contractor can perform the necessary modifications, but engineering drawings must precisely define the scope of work.

INTERIM CONTROLS

During the period following completion of the Southeast WPCP improvements but prior to the implementation of the Citywide Control System, certain facilities will require interim monitoring and controls system. Specific facilities now identified under this category are the North Shore Pump Station, Channel Pump Station, and Southeast Lift Station. During the progress of design and construction of the various pollution control elements, timing constraints will likely cause other facilities to be added to this list.

The above facilities are presently designed with their local dedicated controls only, and have no provision of remote control or flow adjustments from a central location. Since these facilities will largely be unattended, there is a definite need for continous monitoring and control of these facilities from a master station at the Southeast WPCP. An interim control system is necessary not only for adjusting pumped flows for optimization of storage and treatment, but also for continuous surveillance of the remote facilities for any abnormal conditions.

The principal objectives of the interim control system are to provide control of the Channel Pump Station, North Shore Pump Station, and the Southeast Lift Station from the Southeast WPCP, to gather data for future use from storage and pumping facilities, and to provide training, debugging, and operational experience directly applicable to the design and operation of the future Citywide Control System.

The following paragraphs summarize the data monitoring needs, system component requirements, and costs of the recommended interim control system. The recommended system includes a master control station at the Southeast WPCP, remote terminal units at the designated remote facilities, and the required communication link for interim monitoring and control. The major portion of the equipment recommended for the interim system will be usable as part of the ultimate Citywide Control System. Those items which cannot be reused can be sold at the time the Citywide Control System is installed, thus reducing the unrecovered costs of the interim system.

Data Monitoring Needs

It is recommended that the monitoring of various facilities under interim control should include the following parameters:

1. Pump station suction channel levels
2. Pumping rate (each pump)
3. Status of individual pumping units ("running" or "not running")
4. Status of inlet gates (percent open, ready/out of service, etc.)
5. Storage levels at various critical locations within the transport/storage facilities
6. Status of transport/storage gates (percent open, ready/out of service, etc.)
7. Alarms as recommended for each facility in Appendix D

In addition to the above, the interim system should also include certain selected transport data, presently monitored by the San Francisco Hydraulic and Hydrologic Data Acquisition and Recording (SFHHDAR) System.

The SFHHDAR System monitors the sewer levels and tidal conditions. It also collects rainfall data from various in-City and remote raingages. While the exact nature and extent of data necessary for interim controls can only be ascertained during the design phase, it is recommended that levels at critical locations within major trunk sewers presently monitored by the SFHHDAR System, should also be monitored by the interim control system.

Communication Links

The communication network recommended for the Citywide Control System conforms to standards which have been defined by the various telephone utilities operating in the United States. These standards permit procurement of communication channels with confidence that compatible equipment can be added as necessary under normal competitive bidding procedures. Therefore the fiberoptic system linking the North Shore and Channel Outfalls Consolidation facilities with Southeast WPCP should be installed as part of the interim work with channel units as required. The fiberoptic cable will be installed in an existing conduit which was provided as part of the outfalls consolidation work. Appendix H provides basic specification information for the recommended fiberoptic equipment.

Master Station

A computerized master station should be installed at the Southeast WPCP. The master station will include a black and white cathode ray tube (CRT) with keyboard, a logging typer, and an IBM compatible magnetic tape unit. Master station software will provide the following functions.

1. Scan each remote terminal at 5-second intervals to request transfer of data.

2. Store all equipment statuses (digital inputs) and values (analog inputs) in memory.

3. Time tag all alarms and alarm returns; store in memory, log on typer, and record on tape.

4. Integrate analog inputs, representing flows, over 24-hour periods beginning at 8 a.m. each day; log 24-hour flow at 8 a.m. and record on tape.

5. Average each analog input over 5-minute interval and record on tape.

6. Display any discrete input or analog input on CRT when requested.

7. Transmit any discrete output or analog output on initiation from CRT.

8. Check related digital inputs for unreasonable combinations of true and false states.

9. Test all analog inputs for high, high-high, low, and low-low values and treat as alarms.

10. Provide audible signal and alarm acknowledge sequence. When alarm is acknowledged audible will silence and CRT will display alarm summary in reverse order of occurrence.

11. Provide means for initiation of all CRT functions.

The master station should be turned over to the contractor for the Citywide Control System with the understanding that he is free to reuse this equipment as an area control center or sell it as he sees fit.

Remote Terminal Units

Each remote facility listed above will require a remote terminal unit (RTU) not only for interim but also for ultimate control system needs. The RTUs are required to provide the necessary interface between the master controller and the local dedicated controls at each facility. There are a number of commercial units on the market that could be used for the interim system. Many of these units are proprietary in nature and if allowed would most likely not be reusable in the citywide system. The Institute of Electrical and Electronic Engineers (IEEE), under sponsorship of the U.S. Bureau of Standards and the U.S. Atomic Energy Commission, have developed a standard remote terminal which is available from a number of suppliers. This standard remote terminal called CAMAC is entirely suitable for both the interim and the citywide systems.

Although the CAMAC remote terminals are more expensive than the minimum capability terminals that would suffice for interim system, they are no more expensive than those that would ultimately be required for the citywide system. Their use is, therefore, recommended in order to ensure that terminals supplied under the interim contract can be utilized for the citywide system.

Costs of Interim Controls

Estimated costs of the interim control system are given in Table 8-3. As shown in the table, the cost components include the interim telemetry costs and the costs of the modifications required to the Channel Pump Station and North Shore Pump Station controls. These modifications, described in Appendix A, are necessary for establishing the required interfaces for monitoring and control of the above pump stations.

Implementation of Interim Controls

Based on discussion with the City staff, it appears that the Southeast WPCP will be ready to accept flows from the North Shore and Channel Pump Stations by the second quarter of 1982. Ideally, the interim control system should also be operational by that time. The completion of the interim control system within this short time span is not possible; nevertheless, an accelerated design and construction schedule would obviously be a great help towards completing this project soon after the commissioning of the expanded Southeast WPCP. It is, therefore, essential that immediate steps be taken to receive the State and United States Environmental Protection Agency (USEPA) funding for the interim control system design work.

Table 8-3. Estimated Costs of the Interim Control System - ENR 3800

Component	Capital costs,[a] dollars
Material	
Data acquisition and control equipment	
3 CAMAC remote terminals	27,000
1 master station computer	31,000
1 IBM compatible magnetic tape	16,000
1 CRT terminal (black and white)	2,000
1 logging typer	4,000
Communication equipment	
5 optical interface units	13,000
3 channel bank sets (type T1)	5,000
4 data port units	6,000
4 voice channel units	1,000
4 telephone sets	500
27,000 feet fiberoptic cable	35,000
Pump station modifications[b]	
Flow controllers	18,000
Annunciators	7,000
Additional instrumentation	10,000
Programmable logic controller program modifications	5,000
Miscellaneous interface hardware	10,000
Subtotal, material costs	190,500
Labor	
Software	90,000
Cable installation	5,000
Equipment installation	50,000
Job supervision	36,000
Subtotal, labor costs	181,000
Total, material and labor costs	371,500
Contractor's overhead and profit (30 percent)	111,500
Subtotal	483,000
Engineering and contingencies (35 percent)	169,000
Total capital cost	652,000

[a]Based upon Engineering News-Record Construction Cost Index of 3800 (January 1980).

[b]Channel and North Shore Pump Station Control Modifications.

It is estimated that if the design work can begin by March 1981, the interim controls should be constructed and ready for use by the fall of 1982. Thus for the estimated 6-month period between the commissioning of the expanded Southeast WPCP and the completion of the interim controls, the remote pumping facilities will have to be manned, as necessary for manual control.

APPENDIXES

APPENDIX A

CHANNEL AND NORTH SHORE
PUMP STATION MODIFICATIONS

The Channel and North Shore Pump Stations are the existing major facilities which will require modifications in order to be incorporated into the Citywide Control System. Each pump station is provided with a programmable logic controller, a conventional control panel with a comprehensive alarm annunciator, and conventional analog controllers for the various channel levels.

The programmable logic controller should be retained in these two facilities. Minor reprogramming will be required in order to make certain status signals available to the Supervisory Control and Data Acquisition (SCADA) System interface. For example, the "ready" status for each pumping unit is available inside these controllers. A program step will be added to the Modicon Controller which will check the status of all relevant interlocks on each scan cycle. If all are in the correct state, a new output relay will be set to the "true" state. Conversely, if one or more interlocks are not in the correct state, the output relay will be reset to the "false" state. The remote terminal unit (RTU) will constantly monitor the state of this output relay. Certain other statuses required by the SCADA System already appear on the control panel as indicating lamps driven by the programmable controller. Provision of a simple relay, wired in parallel with the indicating lamp, makes this status available to the SCADA System.

The station annunciators presently carry all station alarms. An accessory is available for these annunciators which will provide isolated contact outputs for each alarm point. These contacts may then be wired in series as necessary to provide the required group alarms for the SCADA interface terminals.

Conventional analog controllers presently provide pump sequencing and speed control as a function of suction channel level. Figure A-1 shows the existing arrangement. In order to provide the ability to override the local level control system, the arrangement shown on Figure A-2 is recommended. The new controller, LIC-B, is a computer interface unit having special communications circuitry which makes it very useful in this application. LIC-A has three modes of operation: manual, automatic, and computer. Connecting the output (O) of this controller to the process variable (PV) input causes the output to equal the setpoint (SP) when the controller is in the automatic mode. This operation would be identical to the existing control system. When LIC-A is switched to the computer mode, the station output is directly controlled by the Supervisory Control System.

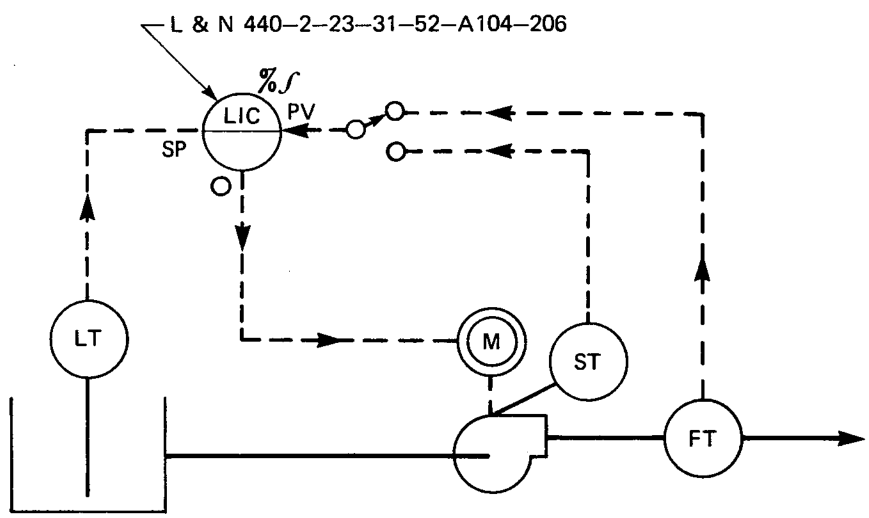


Figure A-1 Channel Pump Station Existing Pump Control (Simplified)

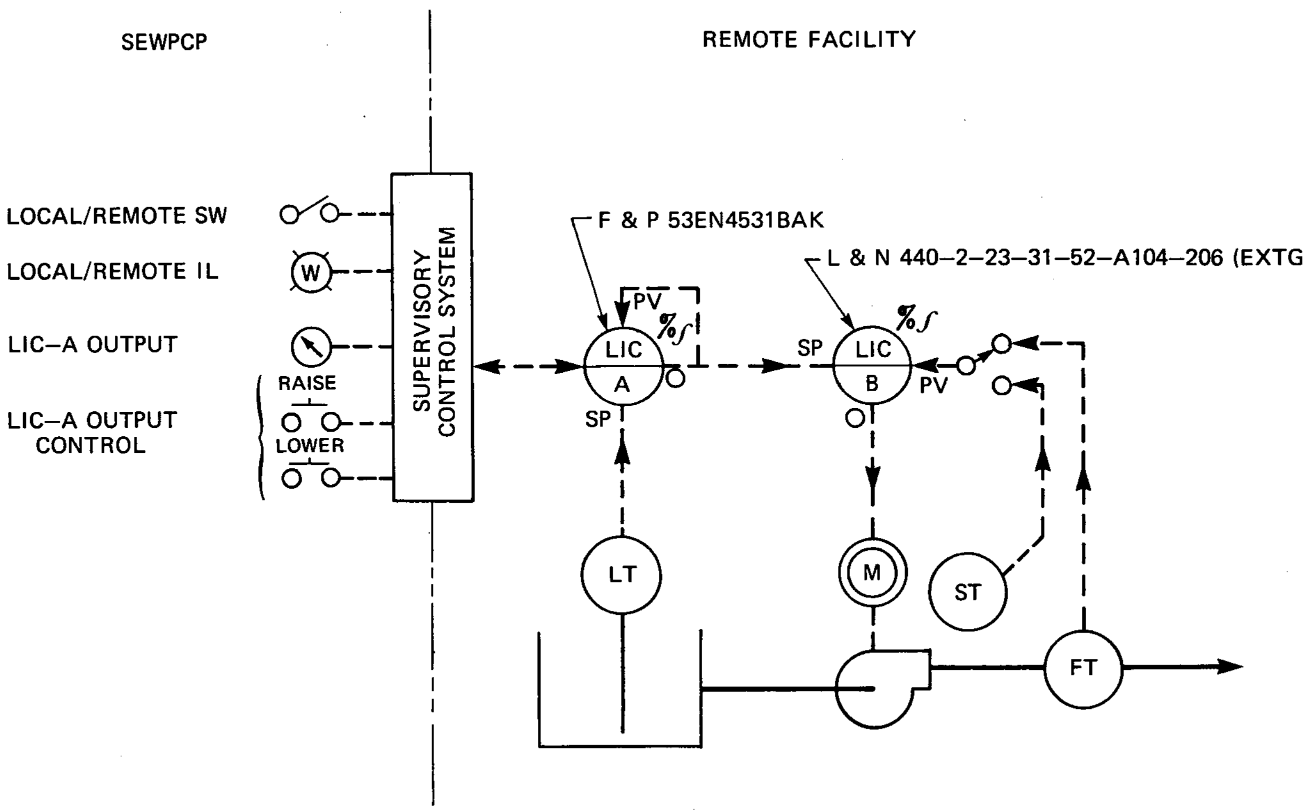


Figure A-2 Channel Pump Station Proposed Pump Control

This permits an operator or a computer at the Southeast Water Pollution Control Plant (SEWPCP) to set the desired flow from the Channel Pump Station and LIC-B will automatically maintain this flow. If the set flow is less than the influent flow, the inlet gate control system will throttle the gates as necessary to limit water levels within the station. A level measurement upstream of the inlet gates will be necessary to inform the operator of the effect of any throttling.

The computer interface station has one other feature which is very important to this type operation. Monitoring circuits provided as part of the supervisory control system will detect any malfunction in the system. If a malfunction occurs, a signal sent to the backup station will cause it to assume the "computer fail" mode. In the computer fail mode, the controller will return to automatic operation, which means that sump level will take over the control of the pumping system even though computer control has been selected.

APPENDIX B

STAGED IMPLEMENTATION OF CONTROL STRATEGIES

This appendix presents recommendations for staged implementation of the control strategies discussed in Chapter 4. The recommendations are based upon the recognition that a full-scale implementation of a predictive control system is not justified until other low cost techniques are fully explored. Therefore, the initial stages attempt to utilize the recommended basic controls to their maximum potential for optimization of the citywide wastewater facilities. The predictive controls evolve gradually in the later stages based upon the experience at each stage.

CONTROL STAGE 1--INTERIM CONTROL

There are a number of facilities presently completed or under construction, including the Southeast Water Pollution Control Plant, Channel Outfalls Consolidation, Channel Pump Station, North Shore Outfalls Consolidation, North Shore Pump Station, and Islais Creek South Side Outfalls Consolidation. These facilities can be operated satisfactorily by an interim control system (see Chapter 8). Overflow structures will continue to be simple weirs and flap gates that do not require central control. The existing San Francisco Hydrologic and Hydraulic Data Acquisition and Recording (SFHHDAR) System will continue to collect data on rainfall and flow levels for recordkeeping purposes. There is no need to tie the raingage network into the interim control system because rainfall rates cannot be effectively used in any control strategy until the master computer is installed.

CONTROL STAGE 2--CITYWIDE REACTIVE CONTROL

By the mid-1980s, the City will have a greatly expanded wastewater operation. The recommended citywide control system will be able to perform several optimization functions using reactive control. For example, different storms have different patterns of basin rainfall ratios (rainfall variation from basin to basin within the City). This can be recognized by the use of raingages; and basins with high rainfall can be allocated more treatment capacity than normal, at the expense of basins with low rainfall. Another function concerns storage levels. Although it is possible to assign a constant value for maximum storage level to each storage facility before wet weather pumps start, it is not optimal. By measuring rainfall, it will be possible to calculate the resulting runoff and the maximum safe storage levels for each period of time; outfall gates and pumps will then be operated accordingly. A third function concerns available treatment capacity. At each period during a storm, flows toward treatment could automatically be adjusted to match available treatment capacity.

In addition to the functions described above, operators' decisions may also be of great value. For instance, the Supervisory Control Center operator may observe conditions favoring manual override of the automated strategies. When such conditions appear, the operator will be able to test the proposed override action on a simulator program to check the likely effects of such override action.

Another computer function which begins at this stage is to gather full information on each overflow occurrence, both to refine operating procedures and to indicate overall effectiveness in reducing overflows.

Without the ability to perform functions such as these, the City will not be able to meet all the requirements of the NPDES permit (Reference 2). Therefore, the City must have the recommended basic controls in Chapter 8. The SFHHDAR System for rain and flow data should be fully merged into the Citywid Control System at this stage.

CONTROL STAGE 3--INTRODUCTORY PREDICTIVE CONTROL

As shown in Chapter 4, overflow reductions and other benefits can be obtained with two rainfall forecasts: a short-term quantitative forcast and a nonquantitative forecast of subsequent rain. In Control Stage 3, low-budget procedures for these forecasts will be attempted.

The short-term quantitative forecasts for Control Stage 3 will be generated by a refined version of RAFORT (Reference 2) or some similar procedure that is almost fully automated and that uses outlying raingages. The Supervisory Control Center operator may make a few nonautomated decisions; for example, if a storm is known to be approaching from the south, the operator may instruct the computer to use gages to the south of the City when making predictions. The subsequent rain forecasts will be obtained directly from the National Weather Service. The computer will compare all forecasts with actual rainfall.

Equipment for Control Stage 3 will include a full network of outlying raingages, wind instruments, and a teletype and telecopier for Weather Service forecasts as shown in Table B-1. The capital cost of this equipment is estimated to be about $133,000. These items should be made operational relatively early so that detailed records of perhaps a year or more of storms may be available to the computer programmers when developing Control Stage 3. Development of computer models and programs will be necessary; an allowance of $150,000 for capital costs plus $5,000 per year for operation and maintenance (O&M) for program updating appears appropriate.

Table B-1. Incremental Costs of Predictive Control, Staged Program - ENR 3800

Description	Capital costs, dollars[a]	Operation and maintenance costs, dollars per year[a]
Control Stage 1 - Interim Control	0	0
Control Stage 2 - Citywide Reactive Control	0	0
Control Stage 3 - Introductory Predictive Control		
Add outlying raingages and wind instruments[b]	130,000	24,000
Add teletype[b]	3,000	1,000
Add telecopier (leased)[b]	0	1,000
Computer modeling and programming	150,000	5,000
Total, Control Stage 3	283,000	31,000
Control Stage 4 - Intermediate Predictive Control		
Add one meteorologist (includes overhead, fringe benefits, etc.)	0	75,000
Add chart facsimile (leased)	0	4,000
Add photographic facsimile (leased)	0	7,000
Add supplemental weather balloons	0	20,000
Total, Control Stage 4	0	106,000
Control Stage 5 - Advanced Predictive Control		
Add second meteorologist	0	75,000
Add radar	570,000	20,000
Add computer modeling and programs	50,000	-[c]
Total, Control Stage 5	620,000	95,000
Total, all stages	903,000	232,000

[a]Costs in this table are incremental costs for predictive control; cost items that are basic to reactive control are given in Table 8-2. Costs are based on an Engineering News-Record Construction Cost Index of 3800 (January 1980). Capital costs include construction contract costs plus 35 percent for contingencies, engineering, and other project costs. Additional details are provided in Chapter 4.

[b]These items should be installed and operated before the rest of Control Stage 3 is implemented so that the computer modelers may have suitable records of actual storms.

[c]Included in cost of meteorologist.

CONTROL STAGE 4--INTERMEDIATE PREDICTIVE CONTROL

The implementation of this stage is contingent upon the results of the preceding stage. If experience during Stage 3 warrants additional efforts toward prediction to improve system performance, Stage 4 should be implemented.

This stage adds one meteorologist who would make forecasts when on duty. The metereologist would obtain all useful data available from the National Weather Service, including upper air charts, satellite photographs, and Sacramento weather radar, in addition to the City-generated data. Supplemental weather balloons would also be provided, starting on a trial basis and continuing if cost-effective. When the meteorologist is off duty, operation would be as in Control Stage 3. Capital costs for Control Stage 4 are essentially zero. For this stage, the major O&M costs are for the meteorologist, balloons, and facsimile machines (leased); these would total about $106,000 per year.

CONTROL STAGE 5--ADVANCED PREDICTIVE CONTROL

The requirements for this stage are somewhat speculative and depend upon the experience gained during Control Stage 4. It appears that for optimum forecasting, a second meteorologist and a weather radar will be needed.

The second meteorologist would provide nearly full-time coverage during stormy periods. A net cost of $45,000 per year is attributable to the second meteorologist, as there will probably be a slight reduction in the costs for other operators in the Citywide Control Center.

Radar would considerably improve the meteorologists' view of the structure, direction, and tendencies of approaching storms. Cost is estimated at $620,000 (total capital, including $50,000 for associated computer modeling and programming). Radar poses a number of questions which should be addressed after experience has been gained at Control Stage 4. Cost-effectiveness is the most important. It is presently not possible to determine the cost-effectiveness of a radar, but a clearer picture is expected by the time this decision must be made. If a radar is used, a site for the antenna will be needed; this site will probably be outside the City because in-City locations are greatly constrained by hills, limited buffer space, and difficulty of operation simultaneously at long ranges and very short ranges from the antenna to the clouds. Because the antenna would be remotely located, data communication between the Citywide Control Center and the antenna site would be required, and the radar would have to be adaptable to remote control. Near the radar antenna, there would be a substantial peak field strength during the transmitted pulses; therefore, the antenna design and location must be selected to avoid any safety problems. Also, an environmental impact report would probably be required.

It is entirely possible that Control Stage 5 may not need the radar and meteorologists as presently envisioned. In the future satellite sensors may provide much more information than present photographs, in which case ground-based radar may become superfluous. It is also conceivable that a fully automated forecasting prodedure may become available that would produce accurate quantitative rainfall forecasts at suitable lead times; if so, there would be no reason to have any meteorologist. Therefore, based upon the experience during the preceding stages, the predictive control operation should be comprehensively studied to determine the best program.

APPENDIX C

WEATHER RADAR INSTRUMENTS

Many radar instruments can be used to observe storms. The least expensive units that can detect rain are probably X-band radars designed for marine navigation; with these radars, intense rainfall causes an echo that (for navigators) is an interfering signal. Among instruments specifically designed for weather observation, the least expensive units are those for aircraft due to the economy of mass production. For greater range and more exact measurement of rainfall echoes, more elaborate instruments are available. Table C-1 summarizes the range of available instruments.

Table C-1. Representative Types of Weather Radar

Characteristic	Wide capability weather radar	Marine navigational radar	Airplane weather radar	Hydrologic weather radar
Band designation	S	X	X	C
Approximate wavelength, cm	10.7	3.2	3.2	5.4
Antenna	12-foot dish	72 by 4 inches	18-inch flat plate or dish	8-foot or 12-foot dish
Azimuth range, degrees	360	360	120 per unit	360
Approximate effective range, statute miles	280	20[a]	30[a]	140[a]
Vertical resolution of clouds	Yes	No	Partial	Yes
Correction for earth's curvature	Automatic	No	Manual	Automatic
Display of echo strength levels	12 contours	Shading	3 contours	6 contours
Stability of echo contours	High	Not contoured	Medium	High
Pulse averaging	Yes	No	No	Yes
Steady display	Yes	No	Yes	Yes
Display visible in normal room light	Yes	Yes	Yes	Yes
Typical manufacturer and model	Raytheon WSR-77	Raytheon RAY-RM-1650/6SR	RCA Primus-300SL	Enterprise Electronics WR100 and added subsystems
Approximate cost of instrument, dollars[b]	700,000	20,000	50,000[c]	275,000

[a]Approximate effective range in the presence of nearby moderate rain. Greater range is possible if no rain exists between the radar and the rain of interest.

[b]1980 price levels. Costs include transmitter, antenna, receiver, signal processor, display, and power supplies. Costs do not include site development, control building, remote control equipment, installation, engineering, administrative costs, or contingencies.

[c]Two units to provide 240-degree scanning. Storms seldom approach from the northeast, so 360-degree scanning is not required.

Generally, as wavelengths increase, antenna sizes increase; minimum detectable raindrop sizes increase, unless compensated by a high-power transmitter and a wide-range receiver; and shadow effects (where a close storm hides a more distant storm) become less severe.

APPENDIX D

CITYWIDE CONTROL SYSTEM PRELIMINARY INPUT/OUTPUT SCHEDULE

The schedule below presents a tentative listing of data that needs to be monitored for the control of the named facilities. The schedule is based upon the most promising physical system elements presently being considered and is intended only as a guide for control system designers. Any change in the nature or configuration of the physical system elements will accordingly change the data communication requirements. These changes should be considered and schedule updated during the predesign phase of the Citywide Control System.

Function	I/O type[a]	Remarks
A. North Shore Outfalls Consolidation System (NSOC) and North Shore Pump Station (Unattended)		
1. NSOC		
Weir structure at Beach		
Upstream water level (coarse)	AI	
Downstream water level (coarse)	AI	
Water level above weir (fine)	AI	
Weir structure at Sansome		
Upstream water level (coarse)	AI	
Downstream water level (coarse)	AI	
Water level above weir (fine)	AI	
Assume three gates at Kearney		
Gate 1 ready/not ready	DI	
Gate 2 ready/not ready	DI	
Gate 3 ready/not ready	DI	
Gate 1 control mode (local/central)	DI	Supervisory control request
Gate 2 control mode (local/central)	DI	
Gate 3 control mode (local/central)	DI	
Gate 1 change control mode (local/central)	DO	Supervisory control available
Gate 2 change control mode (local/central)	DO	
Gate 3 change control mode (local/central)	DO	
Gate 1 position	AI	
Gate 2 position	AI	
Gate 3 position	AI	
Gate 1 operation, set point	AI	
Gate 2 operation, set point	AI	
Gate 3 operation, set point	AI	
Gate 1 control	AO	
Gate 2 control	AO	
Gate 3 control	AO	
Gate trouble alarm (single for all three gates)	DA	
2. North Shore Pump Station (Assumes wet weather pumping)		
Dry weather influent channel level	AI	
Wet weather influent channel level	AI	
Pump station inlet gate position	AI	
T/S level upstream of inlet gate	AI	
Pumped flow (dry weather main) - total	AI	
Pumped flow (wet weather main) - total	AI	
Flow set point	AI	
Flow control	AO	
	DI	Supervisory control request
	DO	Supervisory control accept

[a]The abbreviations used have the following meanings:

AI - Analog input
DI - Digital input
AO - Analog output
DO - Digital output
DA - Digital alarm
PV - Process variable
SP - Set point

Function	I/O type[a]	Remarks
2. North Shore Pump Station (continued)		
Dry weather pump 1 ready	DI	
Dry weather pump 1 running	DI	
Dry weather pump 2 ready	DI	
Dry weather pump 2 running	DI	
Dry weather pump 3 ready	DI	
Dry weather pump 3 running	DI	
Wet weather pump 1 ready	DI	
Wet weather pump 1 running	DI	
Wet weather pump 2 ready	DI	
Wet weather pump 2 running	DI	
Wet weather main pressure	AI	
Dry weather main pressure	AI	
NSPS General high priority alarm	DA	
NSPS General low priority alarm	DA	
NSPS Fire alarm	DA	
NSPS Power outage alarm	DA	
NSPS Security alarm	DA	
Additional discrete alarm (Number 1)	DA	
Additional discrete alarm (Number 2)	DA	
B. Channel Outfalls Consolidation System (COC) and Channel Pump Station (Unattended)		
1. COC		
Assume 12 outfall gates (in four groups) each gate to have following I/O's		
Gate ready/not ready	DI	Supervisory control request
Gate control mode (local/central)	DI	Supervisory control available
Gate change in mode (local/central)	DO	
Gate position	AI	
Gate operation, set point	AI	
Gate control	AO	
Gate trouble alarm (group number 1)	DA	
Gate trouble alarm (group number 2)	DA	
Gate trouble alarm (group number 3)	DA	
Gate trouble alarm (group number 4)	DA	
Assume five weir structures (Sixth north, Division, Fourth south, Fifth, Berry influent bypass), each weir to have the following I/O's		
Upstream water level (coarse)	AI	
Downstream water level (coarse)	AI	
Water level above weir (fine)	AI	
Southside transport/storage level (coarse)	AI	
2. Channel Pump Station (CPS)		
Influent channel level	AI	
Pump station inlet gate position	AI	
T/S level upstream of gate	AI	
Pumped flow (total)	AI	
Flow set point	AI	
Flow control	AO	
	DI	Supervisory control request
	DO	Supervisory control accept

Function	I/O type[a]	Remarks
2. Channel Pump Station (continued)		
Pump 1 ready	DI	
Pump 1 running	DI	
Pump 2 ready	DI	
Pump 2 running	DI	
Pump 3 ready	DI	
Pump 3 running	DI	
Pump 4 ready	DI	
Pump 4 running	DI	
Force main pressure	AI	
CPS general high priority alarm	DA	
CPS general low priority alarm	DA	
CPS fire alarm	DA	
CPS power outage alarm	DA	
CPS security alarm	DA	
Additional discrete alarm (number 1)	DA	
Additional discrete alarm (number 2)	DA	
C. Islais Creek Outfalls Consolidation System (Unattended)		
Assume 12 outfall gates (in four groups) each gate to have following I/O's		
Gate ready/not ready	DI	
Gate control mode (local/central)	DI	Supervisory control request
Gate change in mode (local/central)	DO	Supervisory control accept
Gate position	3 AI	
Gate operation, set point	AI	
Gate control	AO	
Gate trouble alarm (group number 1)	DA	
Gate trouble alarm (group number 2)	DA	
Gate trouble alarm (group number 3)	DA	
Gate trouble alarm (group number 4)	DA	
Assume three weir structures (Selby/Marin, Third north, ICSSOC divider wall) each weir to have		
Upstream water level (coarse)	AI	
Downstream water level (coarse)	AI	
Water level above weir (fine)	AI	
D. Crosstown Pump Station (CTPS) and Reservoir (Attended)		
1. CTPS		
Dry weather influent channel level (treated effluent from SEWPCP)	AI	
Wet weather influent channel level	AI	
Local DW/WW influent channel level (raw wastewater to SEWPCP)	AI	
WW pump station inlet gate position	AI	
T/S level upstream of inlet gate	AI	
Pumped flow (treated effluent) number 1	AI	
Pumped flow (wet weather) number 2	AI	
Pumped flow (to SEWPCP primary headworks) number 3	AI	
Number 1 flow set point	AI	
Number 2 flow set point	AI	

Function	I/O type[a]	Remarks
D. Crosstown Pump Station (continued)		
Number 1 flow control	AO	
	DI	Supervisory control request
	DO	Supervisory control accept
Number 2 flow control	AO	
	DI	Supervisory control request
	DO	Supervisory control accept
Number 3 flow control	AO	
	DI	Supervisory control request
	DO	Supervisory control accept
Treated effluent pump 1 ready	3 DI	
Treated effluent pump 1 running	3 DI	
Treated effluent pump 4 ready	DI	
Treated effluent pump 4 running	DI	
Wet weather pump 1 ready	3 DI	
Wet weather pump 1 running	3 DI	
Wet weather pump 4 ready	DI	
Wet weather pump 4 running	DI	
Local DW/WW pump 1 ready	2 DI	
Local DW/WW pump 1 running	2 DI	
Local DW/WW pump 3 ready	DI	
Local DW/WW pump 3 running	DI	
DW main pressure	AI	
WW main pressure	AI	
All alarms to be grouped in single alarm to SEWPCP (since CTPS will be attended)	DA	
2. Reservoir		
Influent flow to storage	AI	
Flow to SEWPCP primaries	AI	
Washdown flow	AI	
E. Sunnydale Reservoir (Unattended)		Assumes 3 drain pumps
Wet well level	AI	
Wet well inlet gate position	AI	
Reservoir level	AI	
Pumped flow	AI	
Flow set point	AI	
Flow control	AO	
	DI	Supervisory control request
	DO	Supervisory control available
Drain pump 1 ready	2 DI	
Drain pump 1 running	2 DI	
Washwater system ready	DI	
Washwater system running	DI	
Washdown mode/primary mode signal	DI	Washdown running
Change mode	2 DO	Washdown start/stop
Wet weather force main pressure	AI	
General high priority alarm	DA	
General low priority alarm	DA	
Fire alarm	DA	
Power outage alarm	DA	

Function	I/O type[a]	Remarks
E. Sunnydale Reservoir (continued)		
Security alarm	DA	
Additional discrete alarm (number 1)	DA	
Additional discrete alarm (number 2)	DA	
F. Yosemite Reservoir and Pump Station (Unattended)		Assumes three deep sump and three shallow sump pumps
Deep sump water level (sump 1)	AI	
Shallow sump water level (sump 2)	AI	
Shallow sump inlet gate position	AI	
Reservoir levels	3 AI	
Sump 1 pumped flow	AI	
Sump 1 flow set point	AI	
Sump 1 flow control	AO	
	DI	Supervisory control request
	DO	Supervisory control available
Sump 2 pumped flow	AI	
Sump 2 flow set point	AI	
Sump 2 flow control	AO	
	DI	Supervisory control request
	DO	Supervisory control available
Sump 1, pump 1 ready	2 DI	
Sump 1, pump 1 running	2 DI	
Sump 1, pump 3 ready	DI	
Sump 1, pump 3 running	DI	
Sump 2, pump 1 ready	2 DI	
Sump 2, pump 1 running	2 DI	
Sump 2, pump 3 ready	DI	
Sump 2, pump 3 running	DI	
Washdown system ready	DI	System available
Washdown system running	DI	System running
Washdown mode/primary mode signal	DI	System running
Change mode	2 DO	Start/stop
Sump 1, force main pressure	AI	
Sump 2, force main pressure	AI	
General high priority alarm	DA	
General low priority alarm	DA	
Fire alarm	DA	
Power outage alarm	DA	
Security alarm	DA	
Additional discrete alarm 1	DA	
Additional discrete alarm 2	DA	
G. Southeast Water Pollution Control Plant (SEWPCP) (Attended)		
1. Southeast Lift Station		
Wet well level	AI	
Pumped flow	AI	
Pumped flow set point	AI	
Flow control	AO	

Function	I/O Type[a]	Remarks
G. Southeast Water Pollution Control Plant (SEWPCP) (Attended) (continued)		
	DI	Supervisory control request
	DO	Supervisory control available
Inlet gate position	AI	
Pump 1, ready	3 DI	
Pump 1, running	3 DI	
Pump 4, ready	DI	
Pump 4, running	DI	
2. SEWPCP		
Total influent flow	AI	
Headworks WS elevation	AI	
Primary capacity		Keyboard input
Secondary capacity		Keyboard input
H. Southwest Water Pollution Control Plant (Attended)		
Total plant flow	AI	
Influent WS elevation	AI	
Effluent WS elevation	AI	
Primary capacity		Keyboard input
Secondary capacity		Keyboard input
I. Westside Pump Station (Unattended)		
Existing design may be heavily revised. The amount of data is, therefore, yet undefined. Assume the same I/O as for Channel Pump Station. All grouped alarms, however, will go as far as ACC at SWWPCP. The SCC will be capable of processing all alarms in case they are not acknowledged by ACC operator within 30 seconds.		
J. Miscellaneous Stations		
1. Mariposa Pump Station (Unattended)		
Total pumped flow	AI	
Flow set point	AI	
Flow control	AO	
	DI	Supervisory control request
	DO	Supervisory control available
Seven alarms as for other pump stations	7 DA	
2. Hunters Point Pump Station (same as above)		
3. Smaller sewerage system pump stations. There are approximately 10 pump stations throughout the existing sewerage system. No status information is warranted. Only one alarm will be transmitted from each station to the local ACC, (i.e., SWWPCP and SEWPCP as applicable). If not acknowledged by an ACC operator within 30 seconds, the alarm will automatically be transmitted to the SCC.		
4. Raingages One analog signal each from a total of 41 (both existing and proposed) raingages.		

Function	I/O Type[a]	Remarks
J. Miscellaneous Stations (continued)		
5. Sewer Levels Two analogue signals from each of 60 level monitors (approximately).	AI	
6. Additional flow regulator stations Assume about 20 discrete locations with three I/O's each	AI	PV
	AI	SP
	AO	SP control
	DI	Supervisory control request
	DO	Supervisory control available

APPENDIX E

SAMPLE TELEPHONE RATES

Type of Circuit			Cost[a]
3002	c2	FDX	$80/mo + $257 installation
3002	--	FDX	$23/mo + $190 installation
1006	--	FDX	$23/mo + $130 installation

[a] Costs are for point to point within one exchange. Add $21/month for interexchange costs. (Source: Pacific Telephone).

APPENDIX F

ESTIMATING BASIS

Some major hardware items used to arrive at the various control system configurations are listed below:

Item	Manufacturer	Model
Computers	Digital Equipment Corp.	PDP 11/34
Cartridge discs	Digital Equipment Corp.	RK05
Line printer	Digital Equipment Corp.	LP11
Typers	Digital Equipment Corp.	LA120
Color graphic CRT's	Aydin	5217
RTU's and Telem terms	Systems Control	1801
Microwave radios	Motorola	K16BRF
FDM multiplexer	Motorola	MC-400
Coaxial cable	Comm/Scope	P275-500JCA
Fibre optic cable	Galite	6000A1
Digital multiplexer	Canoga Data Systems	CMX100
Magnetic tape drive	Digital Equipment Corp.	TE16

APPENDIX G

TRANSIENT SUPPRESSION

Where light duty contacts must be used to operate inductive loads such as solenoids and motor starters, transient suppression will significantly extend the life of the contacts. Another advantage is that transient suppression significantly reduces the generation of electrical noise caused by switching inductive circuits. Figures G-1 and G-2, on the following page, show suppression circuits normally used with ac and dc coils, respectively.

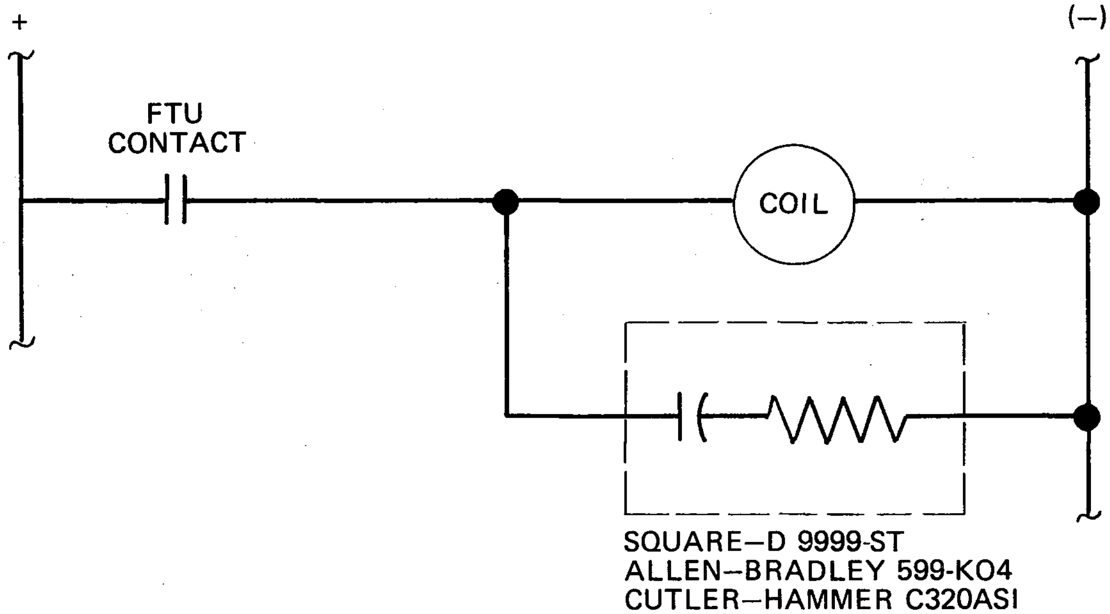


Figure G-1 AC Transient Suppression

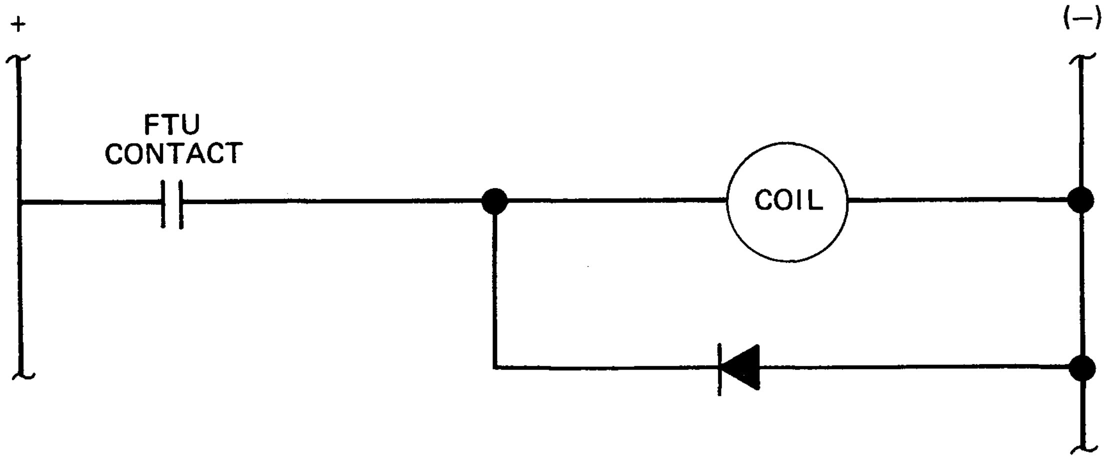


Figure G-2 DC Transient Suppression

APPENDIX H

FIBEROPTIC COMMUNICATION SYSTEM

The following are the suggested specifications for the fiberoptic cable recommended as a communication link between the major facilities.

Cable shall provide four color coded, graded index multimode glass fibers in tight buffer construction, 50-micron core, fused polyethylene-aluminum sheath. Attentuation shall not exceed 4 db/km at 850 nanometers. Optical interface units shall provide communication between each station without repeaters when operating at 1.544 Mb/s (DS 1 rate). Channel banks shall be standard U.S. telephone practice, T1 pulse code, modulation equipment expandable to T1C Mode 3.

APPENDIX I

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